

**Final Environmental Analysis of a
Marine Geophysical Survey by R/V *Marcus G. Langseth*
in the Northeast Pacific Ocean, Summer 2019**

Prepared for

Lamont-Doherty Earth Observatory

61 Route 9W, P.O. Box 1000
Palisades, NY 10964-8000

and

National Science Foundation

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

by

LGL Ltd., environmental research associates

22 Fisher St., POB 280
King City, ON L7B 1A6

13 June 2019

LGL Report FA0169-03

TABLE OF CONTENTS

LIST OF FIGURES.....iv

LIST OF TABLES.....v

ABSTRACT.....vi

LIST OF ACRONYMS.....viii

I PURPOSE AND NEED.....1

 1.1 Mission of NSF.....1

 1.2 Purpose of and Need for the Proposed Action.....1

 1.3 Background of NSF-funded Marine Seismic Research.....2

 1.4 Regulatory Setting.....2

II ALTERNATIVES INCLUDING PROPOSED ACTION.....2

 2.1 Proposed Action.....2

 Project Objectives and Context.....2

 2.1.2 Proposed Activities.....4

 2.1.3 Monitoring and Mitigation Measures.....6

 2.2 Alternative 1: No Action Alternative.....9

 2.3 Alternatives Considered but Eliminated from Further Analysis.....9

 2.3.1 Alternative E1: Alternative Location.....9

 2.3.2 Alternative E2: Use of Alternative Technologies.....9

III AFFECTED ENVIRONMENT.....11

 3.1 Oceanography.....12

 3.2 Protected Areas.....13

 3.3 Marine Mammals.....14

 3.3.1 Mysticetes.....16

 3.3.2 Odontocetes.....20

 3.3.3 Pinnipeds.....29

 3.4 Sea Turtles.....32

 3.4.1 Leatherback Turtle (*Dermochelys coriacea*).....32

 3.5 Seabirds.....33

 3.5.1 Short-tailed Albatross.....34

 3.5.2 Hawaii Petrel.....34

 3.6 ESA-listed Fish, Essential Fish Habitat, and Habitat Areas of Particular Concern.....35

 3.7 Fisheries.....37

IV ENVIRONMENTAL CONSEQUENCES.....37

 4.1 Proposed Action.....37

4.1.1	Direct Effects on Marine Mammals and Sea Turtles and Their Significance	37
4.1.2	Direct Effects on Marine Invertebrates, Fish, and Fisheries, and Their Significance.....	59
4.1.3	Direct Effects on Seabirds and Their Significance.....	66
4.1.4	Indirect Effects on Marine Mammals, Sea Turtles, Seabirds and Fish and Their Significance.....	66
4.1.5	Cumulative Effects	67
4.1.6	Unavoidable Impacts	70
4.1.7	Coordination with Other Agencies and Processes.....	70
4.2	No Action Alternative	71
V	LIST OF PREPARERS.....	72
VI	LITERATURE CITED	73
	LIST OF APPENDICES.....	114
	APPENDIX A: DETERMINATION OF MITIGATION ZONES	
	APPENDIX B: MARINE MAMMAL TAKE CALCULATIONS	
	APPENDIX C: ENSONIFIED AREAS FOR MARINE MAMMAL TAKE CALCULATIONS	

LIST OF FIGURES

	Page
FIGURE 1. Location of the proposed seismic surveys in International Waters of the Northeast Pacific Ocean.....	3

LIST OF TABLES

		Page
TABLE 1.	Level B. Predicted distances to which sound levels ≥ 160 -dB re $1 \mu\text{Pa}_{\text{rms}}$ could be received during the proposed surveys in the Northeast Pacific Ocean.	7
TABLE 2.	Level A threshold distances for different marine mammal hearing groups.	7
TABLE 3.	Sea turtle thresholds recommended by NMFS.	8
TABLE 4.	Summary of Proposed Action, Alternative Considered, and Alternatives Eliminated.	10
TABLE 5.	The habitat, abundance, and conservation status of marine mammals that could occur in or near the proposed seismic survey area in the Northeast Pacific Ocean.	15
TABLE 6.	Fish “species” listed under the ESA off the coasts of Washington and Oregon (NOAA 2018b).	36
TABLE 7.	Densities of marine mammals off Oregon/Washington based on USN (2018).	56
TABLE 8.	Densities and estimates of the possible numbers of individual marine mammals that could be exposed to Level B and Level A thresholds for various hearing groups during the proposed seismic surveys in the Northeast Pacific Ocean during summer 2019.	57
TABLE 9.	ESA determination for marine mammal species expected to be encountered during the proposed surveys in the Northeast Pacific Ocean during summer 2019.	59
TABLE 10.	ESA determination for sea turtle species expected to be encountered during the proposed surveys in the Northeast Pacific Ocean during summer 2019.	59
TABLE 11.	ESA determination for DPSs or ESUs of fish species expected to be encountered during the proposed surveys in the Northeast Pacific Ocean during summer 2019.	66
TABLE 12.	ESA determination for seabird species expected to be encountered during the proposed surveys in the Northeast Pacific Ocean during summer 2019.	67

ABSTRACT

Researchers from the University of Texas at Austin, University of Nevada Reno, University of California San Diego, with funding from the U.S. National Science Foundation (NSF), propose to conduct high-energy seismic surveys from the Research Vessel (R/V) *Marcus G. Langseth* (*Langseth*) in the Northeast Pacific Ocean during summer 2019. The NSF-owned *Langseth* is operated by Columbia University's L-DEO under an existing Cooperative Agreement. The proposed two-dimensional (2-D) and three-dimensional (3-D) seismic surveys would occur in International Waters outside of the U.S. Exclusive Economic Zone (EEZ). The 2-D survey would use a 36-airgun towed array with a total discharge volume of ~6600 in³; the 3-D survey would employ an 18-airgun array with a discharge volume of ~3300 in³. The surveys would occur in water depths ranging from 1400 to 2800 m.

NSF, as the research funding and action agency, has a mission to “promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense...”. The proposed seismic surveys would collect data in support of a research proposal that has been reviewed under the NSF merit review process and identified as an NSF program priority. It would provide data necessary to explore the linkages between complex magma chamber structure, caldera dynamics, fluid pathways, and hydrothermal venting and contribute to a more comprehensive assessment of geohazards for the region that could be used to evaluate earthquake, tsunami and submarine landslide hazards.

This Final Environmental Analysis (EA) addresses NSF's requirements under Executive Order 12114, “Environmental Effects Abroad of Major Federal Actions”, for the proposed NSF federal action. As operator of R/V *Langseth*, L-DEO, on behalf of itself, NSF, the University of Texas at Austin, University of Nevada Reno, and University of California San Diego, will request an Incidental Harassment Authorization (IHA) from the U.S. National Marine Fisheries Service (NMFS) to authorize the incidental (i.e., not intentional) harassment of small numbers of marine mammals should this occur during the seismic surveys. The analysis in this document supports the IHA application process and provides additional information on marine species that are not addressed by the IHA application, including sea turtles, seabirds, fish, and invertebrates that are listed under the U.S. *Endangered Species Act (ESA)*, including candidate species. As analysis on *endangered/threatened* species was included, this document will also be used to support ESA Section 7 consultations with NMFS and the U.S. Fish and Wildlife Service (USFWS). Alternatives addressed in this EA consist of the Proposed Action with issuance of an associated IHA and the No Action alternative, with no IHA and no seismic surveys. This document tiers to the 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 (June 2011) and Record of Decision (June 2012), referred to herein as PEIS. This document also tiers to an EA prepared for a similar seismic survey conducted by R/V *Langseth* in 2012 titled, “Environmental Assessment of Marine Geophysical Surveys by the R/V *Marcus G. Langseth* in the Northeastern Pacific Ocean, June–July 2012” (referred to herein as the 2012 EA; LGL 2012).

Numerous species of marine mammals inhabit the proposed project area in the northeastern Pacific Ocean. Under the U.S. ESA, several of these species are listed as *endangered*, including the North Pacific right, humpback (Central America Distinct Population Segment or DPS), sei, fin, blue, and sperm whales. The *threatened* Mexico DPS of the humpback whale and the *threatened* Guadalupe fur seal could also occur in the proposed project area. ESA-listed sea turtle species that could occur in the project area include the *endangered* leatherback turtle and the *threatened* green turtle. Two ESA-listed seabirds, the *endangered* short-tailed albatross and the *endangered* Hawaiian petrel, could occur in the project area. In addition, several ESA-listed fish species/ populations could potentially occur in the offshore

survey area, including the *endangered* Puget Sound/Georgia Basin DPS of bocaccio, several *threatened* DPSs of steelhead trout, and various *endangered* and *threatened* evolutionarily significant units (ESUs) of chinook, chum, coho, and sockeye salmon.

Potential impacts of the proposed seismic surveys on the environment would be primarily a result of the operation of the airgun array. A multibeam echosounder and sub-bottom profiler would also be operated during the surveys. Impacts from the Proposed Action would be associated with increased underwater anthropogenic sounds, which could result in avoidance behavior by marine mammals, sea turtles, seabirds, and fish, and other forms of disturbance. An integral part of the planned surveys is a monitoring and mitigation program designed to minimize potential impacts of the proposed activities on marine animals present during the proposed surveys, and to document, as much as possible, the nature and extent of any effects. Injurious impacts to marine mammals, sea turtles, and seabirds have not been proven to occur near airgun arrays or the other types of sound sources to be used. However, a precautionary approach would still be taken, and the planned monitoring and mitigation measures would reduce the possibility of any effects.

Protection measures designed to mitigate the potential environmental impacts to marine mammals, sea turtles, and seabirds would include the following: ramp ups; typically two (but a minimum of one) dedicated observers maintaining a visual watch during all daytime airgun operations; two observers before and during ramp ups during the day; no start ups during poor visibility or at night unless the exclusion zone (EZ) and passive acoustic monitoring (PAM) have been monitored for 30 min with no detections; PAM via towed hydrophones during both day and night to complement visual monitoring; and power downs (or if necessary shut downs) when marine mammals or sea turtles are detected in or about to enter designated EZ. The acoustic source would also be powered or shut down in the event an ESA-listed seabird would be observed diving or foraging within the designated EZ. Observers would also watch for any impacts the acoustic sources may have on fish. L-DEO and its contractors are committed to applying these measures in order to minimize effects on marine mammals, sea turtles, seabirds, and fish, and other potential environmental impacts. Ultimately, survey operations would be conducted in accordance with all applicable international, U.S. federal, and state regulations, including IHA and Incidental Take Statement (ITS) requirements.

With the planned monitoring and mitigation measures, unavoidable impacts to each species of marine mammal and sea turtle that could be encountered would be expected to be limited to short-term, localized changes in behavior and distribution near the seismic vessel. At most, effects on marine mammals would be anticipated as falling within the Marine Mammal Protection Act (MMPA) definition of “Level B Harassment” for those species managed by NMFS. No long-term or significant effects would be expected on individual marine mammals, sea turtles, seabirds, fish, the populations to which they belong, or their habitats. However, NSF is required to request, and NMFS may issue, Level A takes for some marine mammal species although Level A takes are very unlikely. No significant impacts would be expected on the populations of those species for which a Level A take is permitted.

LIST OF ACRONYMS

~	approximately
2-D	two-dimensional
3-D	three-dimensional
ADCP	Acoustic Doppler Current Profiler
AEP	Auditory Evoked Potential
AMVER	Automated Mutual-Assistance Vessel Rescue
BC	British Columbia, Canada
BIA	Biologically Important Area
CA	California
CBD	Convention on Biological Diversity
CCE	California Current Ecosystem
CITES	Convention on International Trade in Endangered Species
DAA	Detailed Analysis Area
dB	decibel
DPS	Distinct Population Segment
EA	Environmental Analysis
EBSA	Ecologically or Biologically Significant Marine Areas
EFH	Essential Fish Habitat
EHV	Endeavour Hydrothermal Vents
EIS	Environmental Impact Statement
EO	Executive Order
ESA	<i>(U.S.) Endangered Species Act</i>
ETOMO	Endeavour Tomography
ETP	Eastern Tropical Pacific
EZ	Exclusion Zone
FM	Frequency Modulated
FONSI	Finding of no significant impact
GIS	Geographic Information System
GoM	Gulf of Mexico
h	hour
HAPC	Habitat Area of Particular Concern
hp	horsepower
Hz	Hertz
IHA	Incidental Harassment Authorization (under MMPA)
in	inch
ITS	Incidental Take Statement
IUCN	International Union for the Conservation of Nature
IWC	International Whaling Commission
JFRHV	Juan de Fuca Ridge Hydrothermal Vents
kHz	kilohertz
km	kilometer
kt	knot
L-DEO	Lamont-Doherty Earth Observatory
LFA	Low-frequency Active (sonar)
m	meter
MBES	Multibeam Echosounder
MCS	Multi-Channel Seismic
MFA	Mid-frequency Active (sonar)
min	minute

MMPA	(U.S.) Marine Mammal Protection Act
MPA	Marine Protected Area
ms	millisecond
MUS	Management Unit Species
NMFS	(U.S.) National Marine Fisheries Service
nmi	nautical mile
NOAA	National Oceanic and Atmospheric Administration
NPOS	Northeast Pacific Ocean Seamounts
NPTZ	North Pacific Transition Zone
NRC	(U.S.) National Research Council
NSF	National Science Foundation
OAWRS	Ocean Acoustic Waveguide Remote Sensing
OBIS	Ocean Biogeographic Information System
OBIS	Ocean Biogeographic Information System
OBS	Ocean Bottom Seismometer
OEIS	Overseas Environmental Impact Statement
OOI	Ocean Observatories Initiative
p or pk	peak
PEIS	Programmatic Environmental Impact Statement
PI	Principal Investigator
PTS	Permanent Threshold Shift
PSO	Protected Species Observer
QAA	Qualitative Analysis Area
rms	root-mean-square
ROV	remotely operated vehicle
R/V	research vessel
s	second
SBP	Sub-bottom Profiler
SEL	Sound Exposure Level (a measure of acoustic energy)
SIO	Scripps Institution of Oceanography
SPL	Sound Pressure Level
SOSUS	(U.S. Navy) Sound Surveillance System
SWFSC	Southwest Fisheries Science Center
t	tonnes
TTS	Temporary Threshold Shift
U.K.	United Kingdom
UNEP	United Nations Environment Programme
UNR	University of Nevada Reno
U.S.	United States of America
USCG	U.S. Coast Guard
USGS	U.S. Geological Survey
USFWS	U.S. Fish and Wildlife Service
UTIG	University of Texas, Institute of Geophysics
μPa	microPascal
vs.	versus
WCMC	World Conservation Monitoring Centre
y	year

I PURPOSE AND NEED

This Final environmental analysis (EA) was prepared under Executive Order 12114, “Environmental Effects Abroad of Major Federal Actions” (EO 12114). The Final EA tiers to the Final Programmatic Environmental Impact Statement (PEIS)/Overseas Environmental Impact Statement (OEIS) for Marine Seismic Research funded by the National Science Foundation or Conducted by the U.S. Geological Survey (NSF and USGS 2011) and Record of Decision (NSF 2012), referred to herein as the PEIS. This Final EA also tiers to an EA prepared for a similar seismic survey conducted by R/V *Langseth* in 2012 titled, “Environmental Assessment of Marine Geophysical Surveys by the R/V *Marcus G. Langseth* in the Northeastern Pacific Ocean, June–July 2012” (referred to herein as the 2012 EA; LGL 2012). The purpose of this Final EA is to provide the information needed to assess the potential environmental impacts associated with the Proposed Action, including the use of an airgun array during the proposed seismic surveys.

The Final EA provides details of the Proposed Action at the site-specific level and addresses potential impacts of the proposed seismic surveys on marine mammals, sea turtles, seabirds, fish, and invertebrates. The analysis in this document supported an 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 IHA would allow the non-intentional, non-injurious “take by harassment” of small numbers of marine mammals¹ during the proposed seismic surveys by Columbia University’s Lamont-Doherty Earth Observatory (L-DEO) in the Northeast Pacific Ocean during summer (July/August) 2019. Per NMFS requirement, small numbers of Level A takes will be requested for the remote possibility of low-level physiological effects; however, because of the characteristics of the Proposed Action and proposed monitoring and mitigation measures, in addition to the general avoidance by marine mammals of loud sounds, Level A takes are considered highly unlikely.

1.1 Mission of NSF

The National Science Foundation (NSF) was established by Congress with the *National Science Foundation Act* of 1950 (Public Law 810507, as amended) and is the only federal agency dedicated to the support of fundamental research and education in all scientific and engineering disciplines. Further details on the mission of NSF are described in § 1.2 of the PEIS.

1.2 Purpose of and Need for the Proposed Action

As noted in the PEIS, § 1.3, NSF has a continuing need to fund seismic surveys that enable scientists to collect data essential to understanding the complex Earth processes beneath the ocean floor. The purpose of the proposed study is to use two-dimensional (2-D) and three-dimensional (3-D) seismic surveying to study the Axial volcano/seamount and associated rift axes off the coast of the Pacific Northwest to understand the 3-D nature of the magmatic reservoirs that set Axial volcano’s framework. The objectives are to create a detailed 3-D image of the main and satellite magma reservoirs, image the

¹ To be eligible for an IHA under the 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.

3-D fracture network and how they influence the magma bodies, and to connect the subsurface observations to the surface features. The proposed activities would collect data in support of a research proposal that has been reviewed through the NSF merit review process and have been identified as NSF program priorities to meet the agency's critical need to foster an understanding of Earth processes.

1.3 Background of NSF-funded Marine Seismic Research

The background of NSF-funded marine seismic research is described in § 1.5 of the PEIS.

1.4 Regulatory Setting

The regulatory setting of this EA is described in § 1.8 of the PEIS, including the

- Executive Order 12114;
- Marine Mammal Protection Act (MMPA);
- Endangered Species Act (ESA).

II ALTERNATIVES INCLUDING PROPOSED ACTION

In this Final EA, two alternatives are evaluated: (1) the proposed seismic surveys and associated issuance of an associated IHA and (2) No Action alternative. Additionally, two alternatives were considered but were eliminated from further analysis. A summary of the Proposed Action, the alternative, and alternatives eliminated from further analysis is provided at the end of this section.

2.1 Proposed Action

The Proposed Action, including project objectives and context, activities, and monitoring/mitigation measures for the proposed seismic surveys, is described in the following subsections.

Project Objectives and Context

Teams of researchers from the University of Texas at Austin Institute for Geophysics (UTIG), the Nevada Seismological Laboratory at the University of Nevada Reno (UNR) and Scripps Institution of Oceanography (SIO) at the University of California San Diego, have proposed to conduct seismic surveys using R/V *Langseth* in the Northeast Pacific Ocean (Fig. 1). The following information provides an overview of the research project objectives associated with the surveys.

The objectives are to create a detailed 3-D image of the main and satellite magma reservoirs that set the Axial volcano's framework, image the 3-D fracture network and how they influence the magma bodies, and to connect the subsurface observations to the surface features. The main goal of the seismic program proposed by UTIG, UNR, and SIO is to explore linkages between complex magma chamber structure, caldera dynamics, fluid pathways, and hydrothermal venting. To achieve the project goals, the Principal Investigators (PI) Drs. A. Arnulf (UTIG), G. Kent and A. Kell (UNevada), and A. Harding (SIO) propose to conduct a 3-D multichannel seismic survey (MCS) of the Axial volcano and associated rift axes, plus eight 15-km-long source-receiver offset 2-D reflection profiles to look at the deep-seated structure of magma delivery.

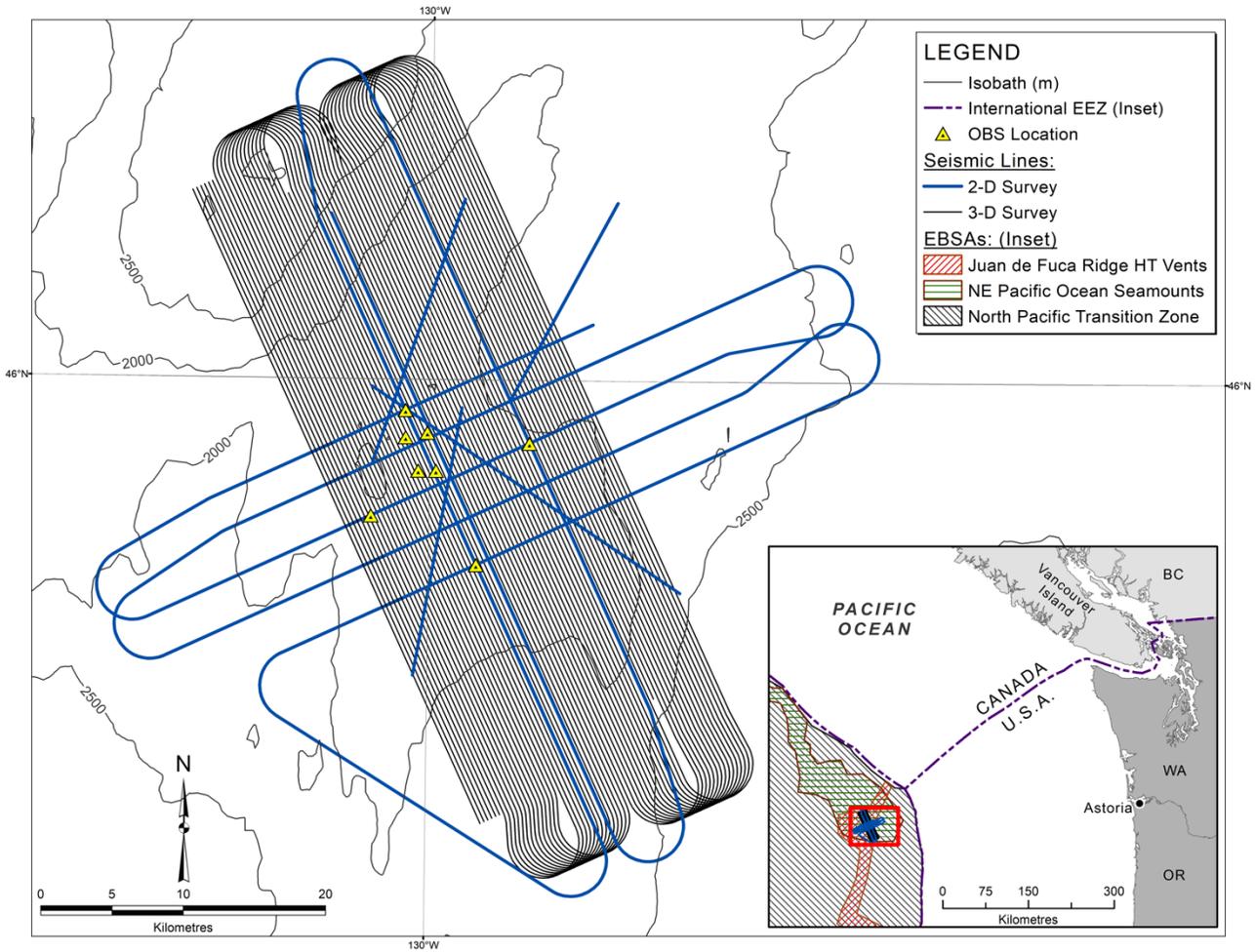


FIGURE 1. Location of the proposed seismic surveys in International Waters of the Northeast Pacific Ocean. HT = Hydrothermal. EBSA = Ecologically or Biologically Significant Marine Areas. EEZ = Exclusive Economic Zone. OBS = Ocean Bottom Seismometer.

2.1.2 Proposed Activities

2.1.2.1 Location of the Survey Activities

The proposed survey would occur within $\sim 45.5\text{--}46.5^\circ\text{N}$, $\sim 129.5\text{--}130.5^\circ\text{W}$. Representative survey tracklines are shown in Figure 1. As described further in this document, however, some deviation in actual track lines, including the order of survey operations, could be necessary for reasons such as science drivers, poor data quality, inclement weather, or mechanical issues with the research vessel and/or equipment. Thus, for the surveys, the tracklines could occur anywhere within the coordinates noted above. The surveys are proposed to occur in International Waters ranging in depth from 1400 to 2800 m.

2.1.2.2 Description of Activities

The procedures to be used for the proposed marine geophysical surveys would be similar to those used during previous surveys by L-DEO and would use conventional seismic methodology. The survey would involve one source vessel, R/V *Langseth*. R/V *Langseth* would tow hydrophone streamers to record seismic signals generated by airgun arrays firing at a shot interval of 37.5 m. During the 3-D survey, two arrays consisting of 18 airguns each, with a discharge volume of $\sim 3300\text{ in}^3$, would be towed at a depth of 10 m, and would fire alternately. During the 2-D survey, the array would consist of 36 airguns with a discharge volume of $\sim 6600\text{ in}^3$ that would be towed at a depth of 10–12 m. The receiving system would consist of hydrophone streamers and up to eight ocean bottom seismometers (OBSs), which R/V *Langseth* would deploy upon arrival to the survey area. Four 6-km long hydrophone streamers would be used during 3-D data acquisition and one 15-km long streamer would be employed for 2-D data acquisition. A longer streamer allows for accurate measurements of seismic velocities and provides a large amount of data redundancy for enhancing seismic images during data processing. The OBSs are long-term broadband instruments that would be left out for ~ 1 year and recovered by another vessel; they have a height and diameter of ~ 1 m, with an 80 kg anchor.

R/V *Langseth* would first deploy the four 6-km streamers and airguns to conduct the 3-D MCS survey to examine the Axial volcano and associated rift axes within an approximate 17×40 km area. The 3-D survey would consist of a racetrack formation with 57 40-km long lines and a turning diameter of 8.5 km; no airguns would be firing during turns. The survey speed would be ~ 4.5 kt for the 3-D survey. The airgun array and streamers would then be recovered, and one 15-km streamer would be deployed along with the airguns to acquire eight ~ 26 -km-long source-receiver offset 2-D reflection profiles that would look at deep-seated structure of magma delivery. During the 2-D survey, the airguns would be firing during turns to the next line, and the survey speed would be ~ 4.2 kt. As previously noted, the location of the survey lines could shift from what is currently depicted in Figure 1 depending on factors such as science drivers, poor data quality, weather, etc.

As the airgun arrays are towed along the survey lines, the OBSs would receive and store the returning acoustic signals internally for later analysis, and the hydrophone streamer(s) would transfer the data to the on-board processing system. A maximum of ~ 3760 km of transect lines would be surveyed in the Northeast Pacific Ocean: ~ 3196 km during the 3-D survey (including run ins and run outs) and ~ 564 km during the 2-D survey. There could be additional seismic operations associated with turns, airgun testing, and repeat coverage of any areas where initial data quality is sub-standard. In the take calculations (see § 4.1.1.5), 25% has been added in the form of operational days which is equivalent to adding 25% to the proposed line km to be surveyed. The entire survey would occur in deep (>1000 m) water.

In addition to the operations of the airgun arrays, a multibeam echosounder (MBES), sub-bottom profiler (SBP), and Acoustic Doppler Current Profiler (ADCP) would be operated from R/V *Langseth* continuously during the seismic surveys, but not during transit to and from the survey area. All planned geophysical data acquisition activities would be conducted by L-DEO with on-board assistance by the scientists who have proposed the studies. The vessel would be self-contained, and the crew would live aboard the vessel.

2.1.2.3 Schedule

The proposed surveys would be expected to last for 33 days, including ~19 days of seismic operations (~16 days for the 3-D survey; 3 days for the 2-D survey), 7 days of equipment deployment/retrieval, ~3 days of operational contingency time (e.g., infill, weather delays, etc.), ~2 days for turns (no airguns firing) during the 3-D survey, and ~2 days of transit. R/V *Langseth* would leave out of and return to port in Astoria, OR, during summer (July/August) 2019.

As R/V *Langseth* is a national asset, NSF and L-DEO strive to schedule its operations in the most efficient manner possible; schedule efficiencies are achieved when regionally occurring research projects are scheduled consecutively and non-operational transits are minimized. Because of the nature of the NSF merit review process and the long timeline associated with the ESA Section 7 consultation and IHA processes, not all research projects or vessel logistics are identified at the time the consultation documents are submitted to federal regulators; typically, however, these types of details, such as port arrival/departure locations, are not a substantive component of the consultations.

Seasonality of the proposed survey operations would likely not affect the ensuing analysis, because the best available species densities for any time of the year have been used for most species (with the exception of fin whales and pinnipeds, for which summer/fall densities were used).

2.1.2.4 Vessel Specifications

R/V *Langseth* is described in § 2.2.2.1 of the PEIS. The vessel speed during seismic operations would be ~4.2 kt (~7.8 km/h) during the 2-D survey and ~4.5 km kt (~8.3 km/h) during the 3-D survey.

2.1.2.5 Airgun Description

During the surveys, R/V *Langseth* would tow four strings with 36 airguns (plus 4 spares). During the 2-D survey, all four strings, totaling 36 active airguns with a total discharge volume of 6600 in³, would be used. During the 3-D survey, two strings consisting of 18 airguns with a total volume of ~3300 in³, would fire alternately. The airgun arrays are described in § 2.2.3.1 of the PEIS, and the airgun configurations are illustrated in Figures 2-11 to 2-13 of the PEIS. The array would be towed at a depth of 10 m for the 3-D survey and at a depth of 10–12 m for the 2-D survey; the shot interval would be 37.5 m.

2.1.2.6 Additional Acoustical Data Acquisition Systems

Along with the airgun operations, three additional acoustical data acquisition systems (an MBES, SBP, and ADCP) would be operated from R/V *Langseth* during the proposed surveys, but not during transits to/from the survey site and port. The ocean floor would be mapped with the Kongsberg EM 122 MBES and a Knudsen Chirp 3260 SBP. A Teledyne RDI 75 kHz Ocean Surveyor ADCP would be used to measure water current velocities. These sources are described in § 2.2.3.1 of the PEIS. To retrieve OBSs, an acoustic release transponder (pinger) is used to interrogate the instrument at a frequency of 8–11 kHz, and a response is received at a frequency of 11.5–13 kHz. The burn-wire release assembly is then activated, and the instrument is released to float to the surface from the anchor which is not retrieved. However, OBSs would not be recovered by R/V *Langseth*.

2.1.3 Monitoring and Mitigation Measures

Standard monitoring and mitigation measures for seismic surveys are described in § 2.4.1.1 and 2.4.2 of the PEIS and would occur in two phases: pre-cruise planning and operations. The following sections describe the efforts during both stages for the proposed activities. Numerous papers have been published with recommendations on how to reduce anthropogenic sound in the ocean (e.g., Simmonds et al. 2014; Wright 2014; Dolman and Jasny 2015). Some of those recommendations have been taken into account here.

2.1.3.1 Planning Phase

As discussed in § 2.4.1.1 of the PEIS, mitigation of potential impacts from the proposed activities begins during the planning phase. Several factors were considered during the planning phase of the proposed activities, including:

Energy Source.—Part of the considerations for the proposed marine seismic surveys was to evaluate whether the research objectives could be met with a smaller energy source. The scientific objectives for the proposed surveys could not be met using a smaller source. During the 2-D survey, a strong reflection source is important in order to fully image the bottom of the magma chamber. For the 3-D survey, the proposed source is reduced from the full 36-airgun array to 18 airguns, which is needed to create a detailed 3-D geologic image at depth.

Survey Location and Timing.—The PIs worked with NSF to consider potential times to carry out the proposed surveys, key factors taken into consideration included environmental conditions (i.e., the seasonal presence of marine mammals, sea turtles, and seabirds), weather conditions, equipment, and optimal timing for other proposed seismic surveys using R/V *Langseth*. Few marine mammals are expected to occur in the proposed offshore survey area. Although baleen whales are likely more common in the region during the summer, most are expected to occur closer to shore.

Mitigation Zones.—During the planning phase, mitigation zones for the proposed marine seismic surveys were not derived from the farfield signature but calculated based on modeling by L-DEO for both the exclusion zones (EZ) for Level A takes and safety zones (160 dB re $1\mu\text{Pa}_{\text{rms}}$) for Level B takes. The background information and methodology for this are provided in Appendix A. The proposed 3-D survey would acquire data with the 18-airgun array at a maximum tow depth of 10 m, and the 2-D survey would employ 36 airguns with a tow depth of up to 12 m. L-DEO model results are used to determine the 160-dB_{rms} radius for the 18- and 36-airgun arrays and 40-in³ (mitigation) airgun in deep water (>1000 m) down to a maximum water depth of 2000 m. Table 1 shows the distances at which the 160-dB re $1\mu\text{Pa}_{\text{rms}}$ sound levels are expected to be received for the airgun arrays and the 40-in³ (mitigation) airgun. The 160-dB level is the behavioral disturbance criterion (Level B) that is used by NMFS to estimate anticipated takes for marine mammals.

The thresholds for permanent threshold shift (PTS) onset or Level A Harassment (injury) for marine mammals for impulsive sounds use dual metrics of cumulative sound exposure level (SEL_{cum} over 24 hours) and peak sound pressure levels (SPL_{flat}). Different thresholds are provided for the various hearing groups, including low-frequency (LF) cetaceans (e.g., baleen whales), mid-frequency (MF) cetaceans (e.g., most delphinids), high-frequency (HF) cetaceans (e.g., harbor porpoise and *Kogia* spp.), phocids underwater (PW), and otariids underwater (OW). As required by the *Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing* (NMFS 2016a, 2018a), the largest distance of the dual criteria (SEL_{cum} or Peak SPL_{flat}) was used to calculate takes and Level A threshold distances. Here, SEL_{cum} is used for LF cetaceans, and Peak SPL is used for all other hearing groups (Table 2).

TABLE 1. Level B. Predicted distances to which sound levels ≥ 160 -dB re $1 \mu\text{Pa}_{\text{rms}}$ could be received during the proposed surveys in the Northeast Pacific Ocean. The 160-dB criterion applies to all hearing groups of marine mammals.

Source and Volume	Maximum Tow Depth (m)	Water Depth (m)	Predicted distances (in m) to the 160-dB Received Sound Level ¹
Single Bolt airgun, 40 in ³	12	>1000 m	431
2 strings, 18 airguns, 3300 in ³	10	>1000 m	3758
4 strings, 36 airguns, 6600 in ³	12	>1000 m	6733

¹ Distance is based on L-DEO model results.

TABLE 2. Level A threshold distances for different marine mammal hearing groups. As required by NMFS (2016a, 2018a), the largest distance (in bold) of the dual criteria (SEL_{cum} or Peak SPL_{flat}) was used to calculate takes and Level A threshold distances.

Level A Threshold Distances (m) for Various Hearing Groups					
	Low-Frequency Cetaceans	Mid-Frequency Cetaceans	High-Frequency Cetaceans	Phocid Pinnipeds	Otariid Pinnipeds
18-airgun array; 3300 in ³					
PTS SEL_{cum}	75.6	0	0.3	2.9	0
PTS Peak	23.2	11.2	118.7	25.1	9.9
36-airgun array; 6600 in ³					
PTS SEL_{cum}	426.9	0	1.3	13.9	0
PTS Peak	38.9	13.6	268.3	43.7	10.6

Table 3 shows the distances at which the 175- and 195-dB re $1\mu\text{Pa}_{\text{rms}}$ sound levels are expected to be received for the 18- and 36-airgun arrays and a single airgun, based on L-DEO modeling; the 195-dB distance would be used as the EZ for sea turtles, as required by NMFS, and the 175-dB level is used by NMFS, as well as USN (2017), to determine behavioral disturbance for turtles.

This document has been prepared in accordance with the current National Oceanic and Atmospheric Administration (NOAA) acoustic practices, and the monitoring and mitigation procedures are based on best practices noted by Pierson et al. (1998), Weir and Dolman (2007), Nowacek et al. (2013a), Wright (2014), Wright and Cosentino (2015), and Acosta et al. (2017). At the time of preparation of this document, how the technical guidance would be implemented operationally, along with other potential monitoring and mitigation measures, remains somewhat uncertain. For other recent

TABLE 3. Sea turtle thresholds recommended by NMFS. Predicted distances to which sound levels ≥ 195 - and 175-dB re 1 $\mu\text{Pa}_{\text{rms}}$ could be received during the proposed surveys in the Northeast Pacific Ocean in water depths >1000 m.

Source and Volume	Tow Depth (m)	Predicted distances (in m) to Received Sound Levels ¹	
		195 dB	175 dB
Single mitigation airgun, 40 in ³	12	8 (100 ²)	77
2 strings, 18 airguns, 3300 in ³	10	76 (100 ³)	814
4 strings, 36 airguns, 6600 in ³	12	181 ⁴	1864

¹ Distance is based on L-DEO model results.

² An EZ of 100 m would be used as the shut-down distance for sea turtles, as specified for low-energy sources in the PEIS.

³ Although this is not a low-energy source, an EZ of 100 m would be used as the shut-down distance for sea turtles.

⁴ This shut-down distance would be used as the EZ for the 36-airgun array.

high-energy seismic surveys conducted by L-DEO, NMFS required protected species observers (PSOs) to establish and monitor a 500-m EZ for power downs and to monitor an additional 500-m buffer zone beyond the EZ. A power down required the reduction of the full array to a single 40-in³ airgun; a 100-m EZ was established and monitored for shut downs of the single airgun. Enforcement of mitigation zones via power and shut downs would be implemented as described below.

2.1.3.2 Operational Phase

Marine mammals and sea turtles are known to occur in the proposed survey area. However, the number of individual animals expected to be approached closely during the proposed activities are expected to be relatively small in relation to regional population sizes, especially that far offshore. To minimize the likelihood that potential impacts could occur to the species and stocks, monitoring and mitigation measures proposed during the operational phase of the proposed activities, which are consistent with the PEIS and past IHA and incidental take statement (ITS) requirements, include:

1. monitoring by PSOs for marine mammals, sea turtles, and ESA-listed seabirds diving near the vessel, and observing for potential impacts of acoustic sources on fish;
2. passive acoustic monitoring (PAM);
3. PSO data and documentation; and
4. mitigation during operations (speed or course alteration; power-down, shut-down, and ramp-up procedures; and special mitigation measures for rare species, species concentrations, and sensitive habitats).

Five independently contracted PSOs would be on board the survey vessel with rotating shifts to allow two observers to monitor for marine species during daylight hours, and one observer to conduct PAM during day- and night-time seismic operations. The proposed operational mitigation measures are standard for all high-energy seismic cruises, per the PEIS, and are described in the IHA application, and

therefore are not discussed further here. Special mitigation measures were considered for this cruise. It is unlikely that concentrations of large whales would be encountered within the 160-dB isopleth, but if they were, they would be avoided. It is anticipated that NMFS will waive the shutdown requirement for the following dolphin general (*Tursiops*, *Delphinus*, *Lagenorhynchus*, *Lissodelphis*, *Stenella*, *Grampus*). With the proposed monitoring and mitigation provisions, potential effects on most, if not all, individuals would be expected to be limited to minor behavioral disturbance. Those potential effects would be expected to have negligible impacts both on individual marine mammals and on the associated species and stocks. Ultimately, survey operations would be conducted in accordance with all applicable U.S. federal regulations, including IHA and ITS requirements.

2.2 Alternative 1: No Action Alternative

An alternative to conducting the Proposed Action is the “No Action” alternative, i.e., do not issue an IHA and do not conduct the research operations (Table 4). Under the “No Action” alternative, NSF would not support L-DEO to conduct the proposed research operations. From NMFS’ perspective, pursuant to its obligation to grant or deny permit applications under the MMPA, the “No Action” alternative entails NMFS denying the application for an IHA. If NMFS were to deny the application, L-DEO would not be authorized to incidentally take marine mammals. If the research was not conducted, the “No Action” alternative would result in no disturbance to marine mammals attributable to the Proposed Action. Although the No-Action Alternative is not considered a reasonable alternative because it does not meet the purpose and need for the Proposed Action, it is included and carried forward for analysis in § 4.3.

2.3 Alternatives Considered but Eliminated from Further Analysis

Table 4 provides a summary of the Proposed Action, alternative, and alternatives eliminated from further analysis.

2.3.1 Alternative E1: Alternative Location

In support of the project objectives to explore linkages between complex magma chamber structure, caldera dynamics, fluid pathways, and hydrothermal venting, the proposed surveys would target two large magma reservoirs within the Axial Seamount. Preliminary research exists constraining their first order location and shape, providing accurate imaging targets. Thus, this location is ideally suited for the proposed study. There may be alternative sites where the proposed research could occur, however, they would have to be accessible and have been researched in advance to ensure the necessary geologic features were present to support the proposed research objectives; the proposed site is known and accessible.

2.3.2 Alternative E2: Use of Alternative Technologies

As described in § 2.6 of the PEIS, alternative technologies to the use of airguns were investigated to conduct high-energy seismic surveys. At this time, these technologies are still not feasible, commercially viable, or appropriate to meet the Purpose and Need. Additional details about these technologies are given in the Final USGS EA (RPS 2014a).

TABLE 4. Summary of Proposed Action, Alternative Considered, and Alternatives Eliminated.

Proposed Action	Description
Proposed Action: Conduct marine geophysical surveys and associated activities in the Northeast Pacific Ocean	Under this action, research activities are proposed to study earth processes and would involve 2-D and 3-D seismic surveys. Active seismic portions would be expected to take ~19 days, additional operational days would be expected for transit; equipment deployment, maintenance, and retrieval; weather; marine mammal activity; and other contingencies. The affected environment, environmental consequences, and cumulative impacts of the proposed activities are described in § III and IV. The standard monitoring and mitigation measures identified in the PEIS would apply, along with any additional requirements identified by regulating agencies in the U.S. All necessary permits and authorizations, including an IHA, would be requested from regulatory bodies.
Alternatives	Description
Alternative 1: No Action	Under this Alternative, no proposed activities would be conducted and seismic data would not be collected. While this alternative would avoid impacts to marine resources, it would not meet the purpose and need for the Proposed Action. Geological data of scientific value and relevance increasing our understanding of the nature of the magmatic reservoirs, and adding to the comprehensive assessment of geohazards for the Pacific Northwest, such as earthquake, tsunami, and submarine landslide hazards, would not be collected. The collection of new data, interpretation of these data, and introduction of new results into the greater scientific community and applicability of these data to other similar settings would not be achieved. No permits and authorizations, including an IHA, would be needed from regulatory bodies, as the Proposed Action would not be conducted.
Alternatives Eliminated from Further Analysis	Description
Alternative E1: Alternative Location	The Axial Seamount contains two large magma reservoirs; preliminary research has shown the approximate location and shape of these, thus providing accurate imaging targets. The data that would be collected would add to the comprehensive assessment of geohazards for the Northeast Pacific region, such as earthquake, tsunami, and submarine landslide hazards. The proposed science underwent the NSF merit review process, and the science, including the site location, was determined to be meritorious.
Alternative E2: Use of Alternative Technologies	Under this alternative, L-DEO would use alternative survey techniques, such as marine vibroseis, that could potentially reduce impacts on the marine environment. Alternative technologies were evaluated in the PEIS, § 2.6. At this time, however, these technologies are still not feasible, commercially viable, or appropriate to meet the Purpose and Need.

III AFFECTED ENVIRONMENT

As described in the PEIS, Chapter 3, the description of the affected environment focuses only on those resources potentially subject to impacts. Accordingly, the discussion of the affected environment (and associated analyses) focuses mainly on those related to marine biological resources, as the proposed short-term activity has the potential to impact marine biological resources within the project area. These resources are identified in § III, and the potential impacts to these resources are discussed in § IV. Initial review and analysis of the proposed Project activity determined that the following resource areas did not require further analysis in this EA:

- *Air Quality/Greenhouse Gases*—Project vessel emissions would result from the proposed activity; however, these short-term emissions would not result in any exceedance of Federal Clean Air standards. Emissions would be expected to have a negligible impact on the air quality within the proposed survey area;
- *Land Use*—All activities are proposed to occur in the marine environment. Thus, no changes to current land uses or activities in the proposed survey area would result from the Project;
- *Safety and Hazardous Materials and Management*—No hazardous materials would be generated or used during the proposed activities. All Project-related wastes would be disposed of in accordance with international, U.S. state, and federal requirements;
- *Geological Resources (Topography, Geology and Soil)*—The proposed Project would result in very minor disturbance to seafloor sediments from OBS deployments during the surveys; small anchors would not be recovered. The proposed activities would not adversely affect geologic resources;
- *Water Resources*—No discharges to the marine environment that would adversely affect marine water quality are expected in the Project area. Therefore, there would be no impacts to water resources resulting from the proposed Project activity;
- *Terrestrial Biological Resources*—All proposed Project activities would occur in the marine environment and would not impact terrestrial biological resources;
- *Visual Resources*—No visual resources would be expected to be negatively impacted as the proposed activities would be short-term and not visible from shore;
- *Socioeconomic and Environmental Justice*—Implementation of the proposed Project would not affect, beneficially or adversely, socioeconomic resources, environmental justice, or the protection of children. No changes in the population or additional need for housing or schools would occur. Because of the location of the proposed marine activities and distance from shore, human activities in the proposed survey area would be limited to commercial fishing and other vessel traffic. Fishing and vessel traffic, and their potential impacts, are described in further detail in § III and IV. No other socioeconomic impacts would be expected as result of the proposed activities; and
- *Cultural Resources*—There are no cultural resources in the proposed survey area. Thus, no impacts to cultural resources would be expected.

3.1 Oceanography

The proposed survey area occurs in the northeastern Pacific Ocean in International Waters far offshore from the coast of Washington/Oregon. In the North Pacific Ocean, there is a clockwise flow of the central subtropical gyre, and to the north of it, the subarctic gyre flows counterclockwise (Escorza-Treviño 2009). The convergence zone of the subarctic and central gyres, known as the Subarctic Boundary, crosses the western and central North Pacific Ocean at 42°N (Escorza-Treviño 2009). It is in that area that the change in abundance of cold-water vs. warm-water species is the greatest (Escorza-Treviño 2009). Along the U.S. west coast, the Alaska Current flows north along the southeastern coast of Alaska and the Aleutian Peninsula, and the California Current flows south along the coast of California (Escorza-Treviño 2009). The California Current system nurtures offshore waters by mixing with water from the shelf edge (Buchanan et al. 2001).

During winter, spring, summer, and fall of 2017, average sea surface temperatures within the survey area were 9.4, 10.7, 16.8, and 14.7°C, respectively, with minimum and maximum values of 9.0°C and 19.1°C (data unavailable for February, May, June, October and December 2017) (ERDDAP 2018a). Average sea surface temperatures were 9.8 and 16.8°C during spring and summer 2018, respectively, with minimum and maximum temperatures of 8.0 and 19.4° (data unavailable for winter and fall 2018) (ERDDAP 2018a). Acoustic backscatter surveys within ~550 km of the U.S. west coast showed that fish and zooplankton are associated with shallow bathymetry in this area; the highest densities were located in water <4000 m deep (Philbrick et al. 2003). From July–December 2001, offshore primary productivity ranged up to ~250 mgC·m⁻²·d⁻¹ in the euphotic zone (Philbrick et al. 2003). Overall, primary production within the survey area is highest during fall and winter; chlorophyll-a peaks of 164 and 161 mg·m⁻³·d⁻¹ were reported for July and August 2018, respectively (ERDDAP 2018b,c).

A climatic phenomenon called the “Pacific Decadal Oscillation” (PDO) is evident in the Pacific Ocean (Mantua 1999). The PDO is similar to a long-lived El Niño-like pattern of climate variability; it is mainly evident in the North Pacific/North American area, whereas El Niños are typical in the tropics (Mantua 1999). El Niño events do not always influence conditions as far north as Oregon and Washington; during less intense episodes, California is the northern limit of El Niño conditions (Buchanan et al. 2001). PDO “events” persist for 20–30 years, whereas typical El Niño events persist for 6–18 months (Mantua 1999). In the past century, there have been two PDO cycles: “cool” PDO regimes during 1890–1924 and 1947–1976, and “warm” PDO regimes during 1925–1946 and 1977–the mid-1990s (Mantua et al. 1997; Minobe 1997). The latest “cool” period appears to have occurred during the mid-1990s until 2013 (NOAA 2018a).

A mass of warm water, referred to as “the Blob”, formed in the Gulf of Alaska during autumn 2013 and grew and spread across the majority of the North Pacific and Bering Sea during spring and summer 2014, resulting in sea surface temperature anomalies $\geq 4^{\circ}\text{C}$ across the region (Peterson et al. 2016). During autumn 2014, decreased upwelling winds caused a portion of this warm water to travel eastward towards the continental shelf off eastern Alaska and the Pacific Northwest, making the sea surface temperature pattern associated with the Blob resemble a “warm” or “positive” PDO pattern (Peterson et al. 2016). Ongoing effects from “the Blob” were further perturbed by a major El Niño arriving from the south and affecting the region during 2015 and 2016, the combination of which reduced the ecosystem’s productivity and altered marine community structure for several years (Brodeur et al. 2018). As of May 2016, sea surface temperature anomalies in the outer shelf waters off Oregon remained 2°C higher, with indications the trend would likely continue well into 2017 (Peterson et al. 2016). Changes in the eastern North Pacific Ocean marine ecosystem have been correlated with changes in the

PDO. Warm PDOs showed increased coastal productivity in Alaska and decreased productivity off the U.S. west coast, whereas the opposite north-south pattern of marine ecosystem productivity was seen during cold PDOs (Mantua 1999).

During late 2018, sustained unseasonably warm conditions likely caused the formation of a new mass of warm water encompassing a large portion of the Pacific Ocean, emulating “the Blob” and dubbed the “Son of the Blob” (Britten 2018). Such warm-water masses are speculated to be linked to climate change and have been correlated with warmer weather on land, deceased whales and extreme mortality events of other higher-trophic level organisms, occurrences of uncommon marine taxa, widespread toxic algal blooms, and poor feeding conditions for many fish species (Britten 2018; Brodeur et al. 2018). A significant shift in prey availability and feeding habits was observed for anchovy, sardine, mackerel, herring, and smelt species in the Northern California Current ecosystem off the Washington and Oregon coasts, which switched from mainly consuming euphausiids, decapods, and copepods during cool years (2011/2012) to principally consuming gelatinous zooplankton during recent warm years (2015/2016) (Brodeur et al. 2018). While the effects of “the Blob” or the “Son of the Blob” are not yet fully understood, the formation of warm water patches are increasingly common in the Pacific Ocean off the western Canadian and American coasts (Britten 2018).

3.2 Protected Areas

Although efforts are currently underway by the UN General Assembly to devise mechanisms for creating, monitoring and enforcing international and high seas Marine Protected Areas (MPAs) around the world, none have yet been developed for the Northeast Pacific Ocean (Jones 2016; MCI 2018). One MPA occurs ~205 km northeast of the proposed survey area within Canadian waters. The Endeavour Hydrothermal Vents (EHV) were designated as the first MPA under Canada’s *Oceans Act* in 2003. The EHV area is located on the Juan de Fuca Ridge, 250 km offshore from Vancouver Island, and 2250 m below the ocean’s surface. Under the Canadian *Oceans Act*, underwater activities that may result in the disturbance, damage, destruction, or removal of the seabed, or any living marine organism or any part of its habitat, are prohibited (DFO 2018a).

The Convention on Biological Diversity (CBD) has designated three Ecologically and Biologically Significant Areas (EBSAs) that overlap the proposed survey area—the Northeast Pacific Ocean Seamounts (NPOS), Juan de Fuca Ridge Hydrothermal Vents (JFRHV), and North Pacific Transition Zone (NPTZ) (see Fig. 1) (CBD 2016a,b,c).

The NPOS EBSA seamount complexes range along the Cascadia subduction zone, from the Gulf of Alaska to ~480 km off the Oregon coast (CBD 2016a). The Axial-Cobb-Eickelberg NPOS sub-complex at least partially overlaps with the proposed survey area and includes at least seven seamounts (CBD 2016a). This sub-complex features the youngest volcanoes of the NPOS, fissures, hydrothermal vents, sheet flows and pit craters, is surrounded by smaller seamounts, and represents a continuum of biodiversity from north to south in the Northeast Pacific Ocean. It supports several unique or endemic species which are otherwise rare in the Pacific Ocean, such as rock scallop, dense aggregations and abundant populations of deepwater corals and sponges, and large populations of commercially viable fishes, and serves as important feeding or nursery areas (e.g., for white sharks) (CBD 2016a). Seamounts have relatively high biodiversity and up to a third of species occurring on these features may be endemic (de Forges et al. 2000 *in* PFMC 2016). Currents generated by seamounts retain rockfish larvae and zooplankton, a principal food source for rockfish (Genin et al. 1988, Mullineaux and Mills 1997, Haury et al. 2000, and Dower and Perry 2001 *in* PFMC 2016). Deep-sea corals also occur on seamounts

(Monterey Bay National Marine Sanctuary 2005 *in* PFMC 2016).

The JFRHV EBSA includes vent fields and their associated structures on the Juan de Fuca Ridge, Gorda Ridge, and Explorer Ridge beyond the EEZs off the coasts of British Columbia (BC), Washington, Oregon and California, vent fluids, gases, and biological communities (CBD 2016b). The EBSA supports diverse macrofaunal and microbial communities, including aggregations of unique and endemic species, and microbial taxa with rare physiologies (CBD 2016b).

The NPTZ EBSA is a ‘9000-km wide upper water column oceanographic feature bounded to the north and south by thermohaline fronts’ (CBD 2016c). Influenced by El Niño/La Niña events, the Subarctic Frontal Zone in the north and the Subtropical Frontal Zone in the south, the specific latitudinal boundaries of this area change seasonally and interannually, ranging between 40–43°N and 28–34°N and situated further south during northern winters (CBD 2016c). The boundaries of this EBSA are also anticipated to change spatially and temporally in response to climate change. A latitudinal gradient of physical features within the EBSA, such as eddies and frontal zones, produces a highly productive habitat that provides key foraging areas within the North Pacific which attracts many species of pelagic predators, including endangered and commercially valuable species, and serves as a migratory corridor for species such as bluefin tuna and juvenile and adult loggerhead sea turtles (CBD 2016c). The high concentrations of chlorophyll-a within this EBSA supports high primary and secondary productivity, and ultimately a variety of higher-trophic level species, including the aforementioned loggerhead sea turtle, tunas, albatrosses, elephant seal, flying squid, Pacific pomfret, blue shark and sauri, many of which undergo extensive migrations (CBD 2016c).

3.3 Marine Mammals

Thirty-two marine mammal species could occur or have been documented to occur in the marine waters off Oregon and Washington, excluding extralimital sightings or strandings (Fiscus and Niggol 1965; Green et al. 1992, 1993; Barlow 1997, 2003; Mangels and Gerrodette 1994; Von Saunder and Barlow 1999; Barlow and Taylor 2001; Buchanan et al. 2001; Calambokidis et al. 2004; Calambokidis and Barlow 2004). However, only 27 species could occur within the offshore survey area, including 6 mysticetes (baleen whales), 18 odontocetes (toothed whales, such as dolphins), and 3 pinnipeds (seals and sea lions) (Table 5). Six of the species that could occur in the proposed survey area are listed under the ESA as **endangered**, including the sperm, humpback (Central America DPSs), sei, fin, blue, and North Pacific right whales. The **threatened** Mexico DPS of the humpback whale and the **threatened** Guadalupe fur seal could also occur in the proposed survey area.

The following seven species/populations are generally found in coastal waters and are not considered further: the sea otter, gray whale (Eastern North Pacific DPS), Southern Resident and Northern Resident DPSs of the killer whale, harbor porpoise, harbor seal, California sea lion, and Steller sea lion. It is also very unlikely that gray whales from the **endangered** Western North Pacific DPS would occur in the proposed survey area. Although Steller sea lions sometimes forage in deeper slope and pelagic waters, they generally remain near rookeries during the breeding season and are unlikely to occur as far offshore as the study area even during dispersal. These species could be encountered during transit to and from Astoria. Vagrant ringed seals, hooded seals, and ribbon seals have been sighted or stranded on the coast of California (see Mead 1981; Reeves et al. 2002) and presumably passed through Washington/Oregon waters. A vagrant beluga whale was seen off the coast of Washington (Reeves et al. 2002). In addition, records exist for Perrin’s beaked whale (*Mesplodon perrini*), pygmy beaked whale (*M. peruvianus*), and ginkgo-toothed beaked whale (*M. ginkgodens*) off the coast of

TABLE 5. The habitat, abundance, and conservation status of marine mammals that could occur in or near the proposed seismic survey area in the Northeast Pacific Ocean.

Species	Occurrence in Area	Habitat	Abundance ¹	U.S. ESA ²	IUCN ³	CITES ⁴
Mysticetes						
North Pacific right whale	Rare	Coastal, shelf, offshore	400-500 ⁵	EN	EN	I
Humpback whale	Uncommon	Mainly nearshore and banks	1918	EN/T ⁶	LC	I
Common minke whale	Uncommon	Nearshore, offshore	636	NL	LC	I
Sei whale	Rare	Mostly pelagic	519	EN	EN	I
Fin whale	Common	Slope, pelagic	9029	EN	EN	I
Blue whale	Uncommon	Pelagic and coastal	1647	EN	EN	I
Odontocetes						
Sperm whale	Common	Pelagic, steep topography	1997	EN	VU	I
Pygmy sperm whale	Rare	Deep, off shelf	4111 ⁷	NL	DD	II
Dwarf sperm whale	Rare	Deep, shelf, slope	4111 ⁷	NL	DD	II
Cuvier's beaked whale	Uncommon	Pelagic	3274	NL	LC	II
Baird's beaked whale	Uncommon	Pelagic	2697	NL	DD	I
Blainville's beaked whale	Rare	Pelagic	3044 ⁸	NL	DD	II
Hubb's beaked whale	Rare	Slope, offshore	3044 ⁸	NL	DD	II
Stejneger's beaked whale	Uncommon	Slope, offshore	3044 ⁸	NL	DD	II
Common bottlenose dolphin	Rare	Coastal, shelf, deep	1924	NL	LC	II
Striped dolphin	Rare	Off continental shelf	29,211	NL	LC	II
Short-beaked common dolphin	Uncommon	Shelf, pelagic, mounts	969,861	NL	LC	II
Pacific white-sided dolphin	Common	Offshore, slope	26,814	NL	LC	II
Northern right whale dolphin	Common	Slope, offshore waters	26,556	NL	LC	II
Risso's dolphin	Common	Shelf, slope, mounts	6336	NL	LC	II
False killer whale	Rare	Pelagic	N.A.	NL	NT	II
Killer whale	Common	Widely distributed	240 ⁹ 243 ¹⁰	NL ¹¹	DD	II
Short-finned pilot whale	Rare	Pelagic, high-relief	836	NL	LC	II
Dall's porpoise	Common	Shelf, slope, offshore	25,750	NL	LC	II
Pinnipeds						
Northern fur seal	Uncommon	Coastal, pelagic	620,660 ¹² 14,050 ¹³	NL	VU	N.A.
Guadalupe fur seal	Uncommon	Mainly coastal, pelagic	20,000	T	LC	I
Northern elephant seal	Common	Coastal, pelagic in migration	179,000 ¹⁴	NL	LC	N.A.

N.A. - Species status was not assessed.

¹ Abundance for the California/Oregon/Washington, Eastern North Pacific, or U.S. stock from Carretta et al. (2018), unless otherwise stated.

² U.S. *Endangered Species Act* (NMFS 2018b): EN = Endangered, T = Threatened, NL = Not listed.

³ Classification from the International Union for the Conservation of Nature (IUCN) Red List of Threatened Species (IUCN 2018); EN = Endangered; VU = Vulnerable; LC = Least Concern; DD = Data Deficient.

⁴ Convention on International Trade in Endangered Species of Wild Fauna and Flora (UNEP-WCMC 2018): Appendix I = Threatened with extinction; Appendix II = not necessarily now threatened with extinction but may become so unless trade is closely controlled.

⁵ North Pacific (Jefferson et al. 2015).

⁶ The Central America DPS is endangered; the Mexico DPS is threatened.

⁷ Combined *Kogia* spp.

⁸ All mesoplodont whales (Moore and Barlow 2017; Carretta et al. 2018).

⁹ Eastern North Pacific Offshore stock.

¹⁰ West Coast Transient stock; minimum estimate (Muto et al. 2018).

¹¹ The Southern Resident DPS is listed as endangered; no other stocks are listed.

¹² Eastern Pacific stock (Muto et al. 2018).

¹³ California stock (Carretta et al. 2018).

¹⁴ California breeding stock (Carretta et al. 2018).

California and/or Baja California (MacLeod et al. 2006). These species are unlikely to be seen in the proposed survey area and are not addressed in the summaries below.

Knowledge on the distribution of marine mammals in the pelagic waters where the proposed survey would take place is scarce. However, since 1996, NOAA NMFS Southwest Fisheries Science Center (SWFSC) has periodically conducted large-scale vessel surveys of marine mammals in the California Current Ecosystem (CCE) that include waters off Washington and Oregon out to ~300 nmi (~550 km), including the proposed survey area. Sightings from the 1996, 2001, 2005, and 2008 surveys are archived in the Ocean Biogeographic Information System (OBIS) database; those occurring in the vicinity of the proposed survey area were extracted and are reported below in the individual species descriptions.

Protected species observer sightings from previous L-DEO seismic surveys off Oregon and Washington in 2012 are also provided in the species descriptions below. Those surveys were of the Cascadia thrust zone off Oregon (43–45°N, 124–125°W), southeast of the proposed survey area, the Cascadia subduction zone off Washington (46–47.5°N, 124–126.5°W), northeast of the proposed survey area, and the Juan de Fuca plate (43–38°N, 124–130°W), which extended offshore to near the proposed survey area (RPS 2012a,b,c). Sightings from the August–September 2009 L-DEO Endeavour Tomography (ETOMO) seismic survey in and adjacent to the EHV MPA are also provided in the species descriptions below; that survey occurred north of the proposed survey area, ~250 km southwest of Vancouver Island, Canada (Holst 2017).

General information on the taxonomy, ecology, distribution and movements, and acoustic capabilities of marine mammals are given in § 3.6.1, § 3.7.1, and § 3.8.1 of the PEIS. One of the qualitative analysis areas (QAAs) defined in the PEIS, the BC Coast, is located to the north of the proposed survey area. The general distribution of mysticetes, odontocetes, and pinnipeds off the BC Coast is discussed in § 3.6.3.2, § 3.7.3.2, and § 3.8.3.2 of the PEIS, respectively. In addition, one of the detailed analysis areas (DAAs), S California, is located to the south of the proposed survey area. The general distribution of mysticetes, odontocetes, and pinnipeds off southern California is discussed in § 3.6.2.3, § 3.7.2.3, and § 3.8.2.3 of the PEIS, respectively. The rest of this section deals specifically with species distribution in the proposed survey area.

3.3.1 Mysticetes

3.3.1.1 North Pacific Right Whale (*Eubalaena japonica*)

The North Pacific right whale is one of the most endangered species of whale in the world (Brownell et al. 2001; NMFS 2013a). It summers in the northern North Pacific and Bering Sea, apparently feeding off southern and western Alaska from May to September (e.g., Tynan et al. 2001). The wintering areas for the population are unknown, but have been suggested to include the Hawaiian Islands and the Ryukyu Islands (Allen 1942; Banfield 1974; Gilmore 1978; Reeves et al. 1978; Herman et al. 1980). Whaling records indicate that right whales once ranged across the entire North Pacific north of 35°N and occasionally occurred as far south as 20°N (Kenney 2009). Although right whales were historically reported off the coast of Oregon, occasionally in large numbers (Scammon 1874; Rice and Fiscus 1968), extensive shore-based and pelagic commercial whaling operations never took large numbers of the species south of Vancouver Island (Rowlett et al. 1994). Nonetheless, Gilmore (1956) proposed that the main wintering ground for North Pacific right whales was off the Oregon coast and possibly northern California, postulating that the inherent inclement weather in those areas discouraged winter whaling (Rice and Fiscus 1968).

In the eastern North Pacific Ocean south of 50°N, only 29 reliable sightings were recorded from 1900 to 1994 (Scarff 1986, 1991; Carretta et al. 1994). Rowlett et al. (1994) photographically identified one right whale off Washington on 24 May 1992, 65 km west of Cape Elizabeth, over a water depth of ~1200 m; the same whale was subsequently photographically identified again ~6 h later 48 km west of Destruction Island, in water ~500 m deep. Despite many miles of systematic aerial and ship-based surveys for marine mammals off the coasts of Washington/Oregon/California over the years, only seven documented sightings of right whales were made from 1990 to 2000 (Waite et al. 2003). Two North Pacific right whale calls were detected on a bottom-mounted hydrophone (located in waters 1390 m deep) off the Washington coast on 29 June 2013; no calls by this species were detected at this site in the two previous years of monitoring (Širović et al. 2014). There are no sightings of North Pacific right whales in the OBIS database near the proposed survey area (OBIS 2018).

Because of the small population size and the fact that North Pacific right whales spend the summer feeding in high latitudes, it is unlikely that any would be present in the proposed project area during the period of operations.

3.3.1.2 Humpback Whale (*Megaptera novaeangliae*)

The humpback whale is found throughout all of the oceans of the world (Clapham 2009). The worldwide population of humpbacks is divided into northern and southern ocean populations, but genetic analyses suggest some gene flow (either past or present) between the North and South Pacific (e.g., Baker et al. 1993; Caballero et al. 2001). Geographical overlap of these populations has been documented only off Central America (Acevedo and Smultea 1995; Rasmussen et al. 2004, 2007). Although considered to be mainly a coastal species, humpback whales often traverse deep pelagic areas while migrating (Clapham and Mattila 1990; Norris et al. 1999; Calambokidis et al. 2001).

Humpback whales migrate between summer feeding grounds in high latitudes and winter calving and breeding grounds in tropical waters (Clapham and Mead 1999). North Pacific humpback whales summer in feeding grounds along the Pacific Rim and in the Bering and Okhotsk seas (Pike and MacAskie 1969; Rice 1978; Winn and Reichley 1985; Calambokidis et al. 2000, 2001, 2008). Humpbacks winter in four different breeding areas: (1) along the coast of Mexico; (2) along the coast of Central America; (3) around the main Hawaiian Islands; and (4) in the western Pacific, particularly around the Ogasawara and Ryukyu islands in southern Japan and the northern Philippines (Calambokidis et al. 2008; Bettridge et al. 2015). These breeding areas have been designated as DPSs, but feeding areas have no DPS status (Bettridge et al. 2015; NMFS 2016b). Individuals encountered in the proposed survey area most likely would come from the Central America and Mexico DPSs, although some individuals from the Hawaii DPS may also feed in these waters. There is a low level of interchange of whales among the main wintering areas and among feeding areas (e.g., Darling and Cerchio 1993; Salden et al. 1999; Calambokidis et al. 2001, 2008).

The humpback whale is the most common species of large cetacean reported off the coasts of Oregon and Washington from May to November (Green et al. 1992; Calambokidis et al. 2000, 2004). The highest numbers have been reported off Oregon during May and June and off Washington during July–September. However, off Oregon and Washington, humpbacks occur primarily over the continental shelf and slope during the summer, with few reported in offshore pelagic waters (Green et al. 1992; Calambokidis et al. 2004, 2015; Becker et al. 2012; Menza et al. 2016). Biologically important areas (BIAs) for feeding humpback whales along the coasts of Oregon and Washington, which have been designated from May to November, are all within ~80 km offshore (Calambokidis et al. 2015).

Six humpback whale sightings (8 animals) were made off Washington/Oregon during the June–July 2012 L-DEO Juan de Fuca plate seismic survey; all were well inshore of the proposed survey area (RPS 2012b). There were 98 humpback whale sightings (213 animals) made during the July 2012 L-DEO seismic survey off southern Washington, northeast of the proposed survey area (RPS 2012a), and 11 sightings (23 animals) during the July 2012 L-DEO seismic survey off Oregon, southeast of the proposed survey area (RPS 2012c). There are no sightings of humpback whales near the proposed survey area in the OBIS database (OBIS 2018). No sightings were made near the proposed survey area in the 2014 SWFSC CCE vessel survey (Barlow 2016). Because of their largely coastal distribution in the waters off Oregon and Washington at feeding aggregations during the summer, humpback whales are likely to be uncommonly encountered, if at all, during the proposed survey.

3.3.1.3 Common Minke Whale (*Balaenoptera acutorostrata*)

The minke whale has a cosmopolitan distribution that spans from tropical to polar regions in both hemispheres (Jefferson et al. 2015). In the Northern Hemisphere, the minke whale is usually seen in coastal areas, but can also be seen in pelagic waters during its northward migration in spring and summer and southward migration in autumn (Stewart and Leatherwood 1985). In the North Pacific, the summer range of the minke whale extends to the Chukchi Sea; in the winter, the whales move farther south to within 2° of the Equator (Perrin and Brownell 2009).

The International Whaling Commission (IWC) recognizes three stocks of minke whales in the North Pacific: the Sea of Japan/East China Sea, the rest of the western Pacific west of 180°N, and the remainder of the Pacific (Donovan 1991). Minke whales are relatively common in the Bering and Chukchi seas and in the Gulf of Alaska, but are not considered abundant in any other part of the eastern Pacific (Brueggeman et al. 1990). In the far north, minke whales are thought to be migratory, but they are believed to be year-round residents in coastal waters off the U.S. west coast (Dorsey et al. 1990).

Sightings have been made off Oregon and Washington in shelf and deeper waters (Green et al. 1992; Adams et al. 2014; Carretta et al. 2017). An estimated abundance of 211 minke whales was reported for the Oregon/Washington region based on sightings data from 1991–2005 (Barlow and Forney 2007), whereas a 2008 survey did not record any minke whales while on survey effort (Barlow 2010). The abundance for Oregon/Washington for 2014 was estimated at 507 minke whales (Barlow 2016). There were no sightings of minke whales off Washington/Oregon during the June–July 2012 L-DEO Juan de Fuca plate seismic survey or during the July 2012 L-DEO seismic survey off Oregon, southeast of the proposed survey area (RPS 2012b,c). One minke whale was seen during the July 2012 L-DEO seismic survey off southern Washington, north of the proposed survey area (RPS 2012a). There are no sightings of minke whales near the proposed survey area in the OBIS database (OBIS (2018)). No sightings of minke whales were made near the proposed survey area during the 2014 SWFSC CCE vessel survey (Barlow 2016). Because of their largely coastal distribution in the waters off Oregon and Washington, minke whales are unlikely to be encountered during the proposed survey.

3.3.1.4 Sei Whale (*Balaenoptera borealis*)

The distribution of the sei whale is not well known, but it is found in all oceans and appears to prefer mid-latitude temperate waters (Jefferson et al. 2015). The sei whale is pelagic and generally not found in coastal waters (Jefferson et al. 2015). It is found in deeper waters characteristic of the continental shelf edge region (Hain et al. 1985) and in other regions of steep bathymetric relief such as seamounts and canyons (Kenney and Winn 1987; Gregr and Trites 2001). On feeding grounds, sei whales associate with oceanic frontal systems (Horwood 1987) such as the cold eastern currents in the North Pacific (Perry et al. 1999a). Sei whales migrate from temperate zones occupied in winter to higher

latitudes in the summer, where most feeding takes place (Gambell 1985a). During summer in the North Pacific, the sei whale can be found from the Bering Sea to the Gulf of Alaska and down to southern California, as well as in the western Pacific from Japan to Korea. Its winter distribution is concentrated at ~20°N (Rice 1998).

Sei whales are rare in the waters off California, Oregon, and Washington (Brueggeman et al. 1990; Green et al. 1992; Barlow 1994, 1997). Only 16 confirmed sightings were reported for California, Oregon, and Washington during extensive surveys from 1991–2014 (Green et al. 1992, 1993; Hill and Barlow 1992; Carretta and Forney 1993; Mangels and Gerrodette 1994; Von Sauner and Barlow 1999; Barlow 2003; Forney 2007; Barlow 2010; Carretta et al. 2017). Based on surveys conducted in 1991–2008, the estimated abundance of sei whales off the coasts of Oregon and Washington was 52 (Barlow 2010); for 2014, the abundance estimate was 468 (Barlow 2016). Two sightings of four individuals were made during the June–July 2012 L-DEO Juan de Fuca plate seismic survey off Washington/Oregon (RPS 2012b); these were well inshore of the proposed survey area (~125°W). No sei whales were sighted during the July 2012 L-DEO seismic surveys north and south of the proposed survey area (RPS 2012a,c). There are no sightings of sei whales near the proposed survey area in the OBIS database (OBIS 2018). Sei whales could be encountered during the proposed survey, although this species is generally considered to be rare in these waters.

3.3.1.5 Fin Whale (*Balaenoptera physalus*)

The fin whale is widely distributed in all the world's oceans (Gambell 1985b), but typically occurs in temperate and polar regions from 20–70° north and south of the Equator (Perry et al. 1999b). Northern and southern fin whale populations are distinct and are sometimes recognized as different subspecies (Aguilar 2009). Fin whales occur in coastal, shelf, and oceanic waters. Sergeant (1977) suggested that fin whales tend to follow steep slope contours, either because they detect them readily or because biological productivity is high along steep contours because of tidal mixing and perhaps current mixing. Stafford et al. (2009) noted that sea-surface temperature is a good predictor variable for fin whale call detections in the North Pacific.

Fin whales appear to have complex seasonal movements and are seasonal migrants; they mate and calve in temperate waters during the winter and migrate to feed at northern latitudes during the summer (Gambell 1985b). The North Pacific population summers from the Chukchi Sea to California and winters from California southwards (Gambell 1985b). Aggregations of fin whales are found year-round off southern and central California (Dohl et al. 1980, 1983; Forney et al. 1995; Barlow 1997) and in the summer off Oregon (Green et al. 1992; Edwards et al. 2015). Vocalizations from fin whales have also been detected year-round off northern California, Oregon, and Washington (Moore et al. 1998, 2006; Watkins et al. 2000a,b; Stafford et al. 2007, 2009; Edwards et al. 2015). Based on surveys conducted in 1991–2008, the estimated abundance of fin whales off the coasts of Oregon and Washington was 416 (Barlow 2010); the estimate for 2014 was 3458 (Barlow 2016).

Fin whales are routinely sighted during surveys off Oregon and Washington (Barlow and Forney 2007; Barlow 2010; Adams et al. 2014; Calambokidis et al. 2015; Edwards et al. 2015; Carretta et al. 2017), including in coastal as well as offshore waters. They have also been detected acoustically near the proposed study area during June–August (Edwards et al. 2015). There is one sighting of a fin whale in the OBIS database within the proposed survey area, which was made in August 2005 during the SWFSC Collaborative Survey of Cetacean Abundance and the Pelagic Ecosystem (CSCAPE) Marine Mammal Survey, and several other sightings in adjacent waters (OBIS 2018). Eight fin whale sightings (19 animals) were made off Washington/Oregon during the June–July 2012 L-DEO Juan de Fuca plate

seismic survey, including two sightings (4 animals) in the vicinity of the proposed survey area; sightings were made in waters 2369–3940 m deep (RPS 2012b). Fourteen fin whale sightings (28 animals) were made during the July 2012 L-DEO seismic surveys off southern Washington, northeast of the proposed survey area (RPS 2012a). No fin whales were sighted during the July 2012 L-DEO seismic survey off Oregon, southeast of the proposed survey area (RPS 2012c). Fin whales were also seen off southern Oregon during July 2012 in water >2000 m deep during surveys by Adams et al. (2014). Fin whales are likely to be common in the proposed survey area.

3.3.1.6 Blue Whale (*Balaenoptera musculus*)

The blue whale has a cosmopolitan distribution and tends to be pelagic, only coming nearshore to feed and possibly to breed (Jefferson et al. 2015). Although it has been suggested that there are at least five subpopulations of blue whales in the North Pacific (NMFS 1998), analysis of blue whale calls monitored from the U.S. Navy Sound Surveillance System (SOSUS) and other offshore hydrophones (see Stafford et al. 1999, 2001, 2007; Watkins et al. 2000a; Stafford 2003) suggests that there are two separate populations: one in the eastern and one in the western North Pacific (Sears and Perrin 2009). Broad-scale acoustic monitoring indicates that blue whales occurring in the northeast Pacific during summer and fall may winter in the eastern tropical Pacific (Stafford et al. 1999, 2001).

The distribution of the species, at least during times of the year when feeding is a major activity, occurs in areas that provide large seasonal concentrations of euphausiids (Yochem and Leatherwood 1985). The eastern North Pacific stock feeds in California waters from June–November (Calambokidis et al. 1990; Mate et al. 1999). There are nine BIAs for feeding blue whales off the coast of California (Calambokidis et al. 2015), and core areas have also been identified there (Irvine et al. 2014). Blue whales have been detected acoustically off Oregon (McDonald et al. 1995; Stafford et al. 1998; Von Sauner and Barlow 1999), but sightings are uncommon (Carretta et al. 2018). Densities along the U.S. west coast, including Oregon, were predicted to be highest in shelf waters, with lower densities in deeper offshore areas (Becker et al. 2012; Calambokidis et al. 2015). Buchanan et al. (2001) considered blue whales to be rare off Oregon and Washington. However, based on the absolute dynamic topography of the region, blue whales could occur in relatively high densities off Oregon during July–December (Pardo et al. 2015).

There are no sightings of blue whales within the proposed survey area in the OBIS database; however, the nearest sighting is ~55 km to the southwest (OBIS 2018), and there are several other sightings in adjacent waters (Carretta et al. 2018; OBIS 2018). Satellite telemetry suggests that blue whales are present in waters offshore of Oregon and Washington during fall and winter (Bailey et al. 2009; Hazen et al. 2017). Blue whales could be encountered in the proposed survey area.

3.3.2 Odontocetes

3.3.2.1 Sperm Whale (*Physeter macrocephalus*)

The sperm whale is the largest of the toothed whales, with an extensive worldwide distribution (Rice 1989). Sperm whale distribution is linked to social structure: mixed groups of adult females and juvenile animals of both sexes generally occur in tropical and subtropical waters, whereas adult males are commonly found alone or in same-sex aggregations, often occurring in higher latitudes outside the breeding season (Best 1979; Watkins and Moore 1982; Arnbom and Whitehead 1989; Whitehead and Waters 1990). Males can migrate north in the summer to feed in the Gulf of Alaska, Bering Sea, and waters around the Aleutian Islands (Kasuya and Miyashita 1988). Mature male sperm whales migrate to warmer waters to breed when they are in their late twenties (Best 1979).

Sperm whales generally are distributed over large areas that have high secondary productivity and steep underwater topography, in waters at least 1000 m deep (Jaquet and Whitehead 1996; Whitehead 2009). They are often found far from shore, but can be found closer to oceanic islands that rise steeply from deep ocean waters (Whitehead 2009). Adult males can occur in water depths <100 m and as shallow as 40 m (Whitehead et al. 1992; Scott and Sadove 1997). They can dive as deep as ~2 km and possibly deeper on rare occasions for periods of over 1 h; however, most of their foraging occurs at depths of ~300–800 m for 30–45 min (Whitehead 2003).

Sperm whales are distributed widely across the North Pacific (Rice 1989). Off California, they occur year-round (Dohl et al. 1983; Barlow 1995; Forney et al. 1995), with peak abundance from April to mid-June and from August to mid-November (Rice 1974). Off Oregon, sperm whales are seen in every season except winter (Green et al. 1992).

Oleson et al. (2009) noted a significant diel pattern in the occurrence of sperm whale clicks at offshore and inshore monitoring locations off Washington, whereby clicks were more commonly heard during the day at the offshore site and were more common at night at the inshore location, suggesting possible diel movements up and down the slope in search of prey. Sperm whale acoustic detections were also reported at the inshore site from June through January 2009, with an absence of calls during February to May (Širović et al. 2012). In addition, sperm whales were sighted during surveys off Washington in June 2011 and off Oregon in October 2011 (Adams et al. 2014). There is one sighting of a sperm whale in the vicinity of the survey area in the OBIS database that was made in July 1996 during the SWFSC ORCAWALE Marine Mammal Survey (OBIS 2018), and several other sightings in adjacent waters (Carretta et al. 2018; OBIS 2018). Sperm whale sightings were also made in the vicinity of the proposed survey area during the 2014 SWFSC vessel survey (Barlow 2016). A single sperm whale was sighted during the 2009 ETOMO survey, north of the proposed survey area (Holst 2017). Sperm whales were detected acoustically in waters near the proposed survey area in August 2016 during the SWFSC Passive Acoustics Survey of Cetacean Abundance Levels (PASCAL) study using drifting acoustic recorders (Keating et al. 2018). Sperm whales are likely to be encountered in the proposed survey area.

3.3.2.2 Pygmy and Dwarf Sperm Whales (*Kogia breviceps* and *K. sima*)

The pygmy and dwarf sperm whales are distributed widely throughout tropical and temperate seas, but their precise distributions are unknown as most information on these species comes from strandings (McAlpine 2009). They are difficult to sight at sea, perhaps because of their avoidance reactions to ships and behavior changes in relation to survey aircraft (Würsig et al. 1998). The two species are difficult to distinguish from one another when sighted (McAlpine 2009).

Both *Kogia* species are sighted primarily along the continental shelf edge and slope and over deeper waters off the shelf (Hansen et al. 1994; Davis et al. 1998). Several studies have suggested that pygmy sperm whales live mostly beyond the continental shelf edge, whereas dwarf sperm whales tend to occur closer to shore, often over the continental shelf (Rice 1998; Wang et al. 2002; MacLeod et al. 2004). Barros et al. (1998), on the other hand, suggested that dwarf sperm whales could be more pelagic and dive deeper than pygmy sperm whales. It has also been suggested that the pygmy sperm whale is more temperate and the dwarf sperm whale more tropical, based at least partially on live sightings at sea from a large database from the eastern tropical Pacific (Wade and Gerrodette 1993). This idea is also supported by the distribution of strandings in South American waters (Muñoz-Hincapié et al. 1998).

Pygmy and dwarf sperm whales are rarely sighted off Oregon and Washington, with only one sighting of an unidentified *Kogia* sp. beyond the U.S. EEZ, during the 1991–2014 NOAA vessel surveys (Carretta et al. 2017). This sighting was made in October 1993 during the SWFSC PODS Marine

Mammal Survey ~150 km to the south of the proposed survey area (OBIS 2018). Norman et al. (2004) reported eight confirmed stranding records of pygmy sperm whales for Oregon and Washington, five of which occurred during autumn and winter. It is possible that pygmy or dwarf sperm whales could be encountered within the proposed project area.

3.3.2.3 Cuvier's Beaked Whale (*Ziphius cavirostris*)

Cuvier's beaked whale is probably the most widespread of the beaked whales, although it is not found in polar waters (Heyning 1989). Cuvier's beaked whale appears to prefer steep continental slope waters (Jefferson et al. 2015) and is most common in water depths >1000 m (Heyning 1989). It is mostly known from strandings and strands more commonly than any other beaked whale (Heyning 1989). Its inconspicuous blows, deep-diving behavior, and tendency to avoid vessels all help to explain the infrequent sightings (Barlow and Gisiner 2006). The population in the California Current Large Marine Ecosystem seems to be declining (Moore and Barlow 2013).

MacLeod et al. (2006) reported numerous sightings and strandings along the Pacific coast of the U.S. Cuvier's beaked whale is the most common beaked whale off the U.S. west coast (Barlow 2010), and it is the beaked whale species that has stranded most frequently on the coasts of Oregon and Washington. From 1942–2010, there were 23 reported Cuvier's beaked whale strandings in Oregon and Washington (Moore and Barlow 2013). Most (75%) Cuvier's beaked whale strandings reported occurred in Oregon (Norman et al. 2004).

Four beaked whale sightings were reported in water depths >2000 m off Oregon/Washington during surveys in 2008 (Barlow 2010). None were seen in 1996 or 2001 (Barlow 2003), and several were recorded from 1991 to 1995 (Barlow 1997). One Cuvier's beaked whale sighting was made east of the proposed survey area during 2014 (Barlow 2016). Acoustic monitoring in Washington offshore waters detected Cuvier's beaked whale pulses between January and November 2011 (Širović et al. 2012b in USN 2015). There is one sighting of a Cuvier's beaked whale near the proposed survey area in the OBIS database that was made in July 1996 during the SWFSC ORCAWALE Marine Mammal Survey (OBIS 2018), and several other sightings were made in adjacent waters, primarily to the south and east of the proposed survey area (Carretta et al. 2018; OBIS 2018). Cuvier's beaked whales were detected acoustically in waters near the proposed survey area in August 2016 during the SWFSC PASCAL study using drifting acoustic recorders (Keating et al. 2018). Cuvier's beaked whales could be encountered during the proposed survey.

3.3.2.4 Blainville's Beaked Whale (*Mesoplodon densirostris*)

Blainville's beaked whale is found in tropical and warm temperate waters of all oceans (Pitman 2009). It has the widest distribution throughout the world of all mesoplodont species and appears to be relatively common (Pitman 2009). Like other beaked whales, Blainville's beaked whale is generally found in waters 200–1400 m deep (Gannier 2000; Jefferson et al. 2015). Occasional occurrences in cooler, higher-latitude waters are presumably related to warm-water incursions (Reeves et al. 2002). MacLeod et al. (2006) reported stranding and sighting records in the eastern Pacific ranging from 37.3°N to 41.5°S. However, none of the 36 beaked whale stranding records in Oregon and Washington during 1930–2002 included Blainville's beaked whale (Norman et al. 2004). One Blainville's beaked whale was found stranded (dead) on the Washington coast in November 2016 (COASST 2016).

There are no sightings of Blainville's beaked whales near the proposed survey area in the OBIS database (OBIS 2018). There is one sighting of an unidentified species of Mesoplodont whale near the survey area in the OBIS database that was made in July 1996 during the SWFSC ORCAWALE Marine

Mammal Survey (OBIS 2018). There was one acoustic encounter with Blainville's beaked whales recorded in Quinalt Canyon off Washington in waters 1400 m deep during 2011 (Baumann-Pickering et al. 2014). Blainville's beaked whales were not detected acoustically in waters near the proposed survey area in August 2016 during the SWFSC PASCAL study using drifting acoustic recorders (Keating et al. 2018). Although Blainville's beaked whales could be encountered during the proposed survey, an encounter would be unlikely because the proposed survey area is beyond the northern limits of this tropical species' usual distribution.

3.3.2.5 Stejneger's Beaked Whale (*Mesoplodon stejnegeri*)

Stejneger's beaked whale occurs in subarctic and cool temperate waters of the North Pacific Ocean (Mead 1989). In the eastern North Pacific Ocean, it is distributed from Alaska to southern California (Mead et al. 1982; Mead 1989). Most stranding records are from Alaskan waters, and the Aleutian Islands appear to be its center of distribution (MacLeod et al. 2006). After Cuvier's beaked whale, Stejneger's beaked whale was the second most commonly stranded beaked whale species in Oregon and Washington (Norman et al. 2004).

Stejneger's beaked whale calls were detected during acoustic monitoring offshore Washington between January and June 2011, with an absence of calls from mid-July to November 2011 (Širović et al. 2012b in USN 2015). Analysis of these data suggest that this species could be more than twice as prevalent in this area than Baird's beaked whale (Baumann-Pickering et al. 2014). Stejneger's beaked whales were also detected acoustically in waters near the proposed survey area in August 2016 during the SWFSC PASCAL study using drifting acoustic recorders (Keating et al. 2018). There are no sightings of Stejneger's beaked whales near the proposed survey area in the OBIS database (OBIS 2018). There is one sighting of an unidentified species of Mesoplodont beaked whale near the survey area in the OBIS database that was made during July 1996 during the SWFSC ORCAWALE Marine Mammal Survey (OBIS 2018). Stejneger's beaked whales could be encountered during the proposed survey.

3.3.2.6 Hubbs' Beaked Whale (*Mesoplodon carlhubbsi*)

Hubbs' beaked whale occurs in temperate waters of the North Pacific (Mead 1989). Its distribution appears to be correlated with the deep subarctic current (Mead et al. 1982). Numerous stranding records have been reported for the west coast of the U.S. (MacLeod et al. 2006). Most of the records are from California, but it has been sighted as far north as Prince Rupert, BC (Mead 1989). Two strandings are known from Washington/Oregon (Norman et al. 2004). Hubbs' beaked whales are often killed in drift gillnets off California (Reeves et al. 2002).

There are no sightings of Hubbs' beaked whales near the proposed survey area in the OBIS database (OBIS 2018). There is one sighting of an unidentified species of Mesoplodont whale near the survey area in the OBIS database that was made in July 1996 during the SWFSC ORCAWALE Marine Mammal Survey (OBIS 2018). During the 2016 SWFSC PASCAL study using drifting acoustic recorders, detections were made of beaked whale sounds presumed to be from Hubbs' beaked whales near the proposed survey area during August (Griffiths et al. submitted manuscript cited in Keating et al. 2018). In addition, at least two sightings just to the south of the proposed survey area were reported in Carretta et al. (2018). This species seems to be less common in the proposed survey area than some of the other beaked whales, but it could be encountered during the survey.

3.3.2.7 Baird's Beaked Whale (*Berardius bairdii*)

Baird's beaked whale has a fairly extensive range across the North Pacific, with concentrations occurring in the Sea of Okhotsk and Bering Sea (Rice 1998; Kasuya 2009). In the eastern Pacific, Baird's

beaked whale is reported to occur as far south as San Clemente Island, California (Rice 1998; Kasuya 2009). Baird's beaked whales that occur off the U.S. west coast are of the gray form, unlike some *Berardius* individuals that are found in Alaska and Japan, which are of the black form and thus could be a new species (Morin et al. 2017).

Baird's beaked whale is sometimes seen close to shore where deep water approaches the coast, but its primary habitat is over or near the continental slope and oceanic seamounts (Jefferson et al. 2015). Along the U.S. west coast, Baird's beaked whales have been sighted primarily along the continental slope (Green et al. 1992; Becker et al. 2012; Carretta et al. 2018) from late spring to early fall (Green et al. 1992). The whales move out from those areas in winter (Reyes 1991). In the eastern North Pacific Ocean, Baird's beaked whales apparently spend the winter and spring far offshore, and in June, they move onto the continental slope, where peak numbers occur during September and October. Green et al. (1992) noted that Baird's beaked whales on the U.S. west coast were most abundant in the summer, and were not sighted in the fall or winter. MacLeod et al. (2006) reported numerous sightings and strandings of *Berardius* spp. off the U.S. west coast.

Green et al. (1992) sighted five groups during 75,050 km of aerial survey effort in 1989–1990 off Washington/Oregon spanning coastal to offshore waters: two in slope waters and three in offshore waters. Two groups were sighted during summer/fall 2008 surveys off Washington/Oregon, in waters >2000 m deep (Barlow 2010). Acoustic monitoring offshore Washington detected Baird's beaked whale pulses during January through November 2011, with peaks in February and July (Širović et al. 2012b *in* USN 2015). Baird's beaked whales were detected acoustically near the proposed survey area in August 2016 during the SWFSC PASCAL study using drifting acoustic recorders (Keating et al. 2018). There is one sighting of a Baird's beaked whale near the survey area in the OBIS database that was made in August 2005 during the SWFSC CSCAPE Marine Mammal Survey (OBIS 2018). Baird's beaked whales could be encountered in the proposed survey area.

3.3.2.8 Common Bottlenose Dolphin (*Tursiops truncatus*)

The bottlenose dolphin is distributed worldwide in coastal and shelf waters of tropical and temperate oceans (Jefferson et al. 2015). There are two distinct bottlenose dolphin types: a shallow water type, mainly found in coastal waters, and a deep water type, mainly found in oceanic waters (Duffield et al. 1983; Hoelzel et al. 1998; Walker et al. 1999). Coastal common bottlenose dolphins exhibit a range of movement patterns including seasonal migration, year-round residency, and a combination of long-range movements and repeated local residency (Wells and Scott 2009).

Bottlenose dolphins occur frequently off the coast of California, and sightings have been made as far north as 41°N, but few records exist for Oregon/Washington (Carretta et al. 2017). Three sightings and one stranding of bottlenose dolphins have been documented in Puget Sound since 2004 (Cascadia Research 2011 *in* USN 2015). It is possible that offshore bottlenose dolphins may range as far north as the proposed survey area during warm-water periods (Carretta et al. 2017). Adams et al. (2014) made one sighting off Washington during September 2012. There are no sightings of bottlenose dolphins near the proposed survey area in the OBIS database (OBIS 2018). It is possible, although unlikely, that bottlenose dolphins could be encountered in the proposed survey area.

3.3.2.9 Short-beaked Common Dolphin (*Delphinus delphis*)

The short-beaked common dolphin is found in tropical and warm temperate oceans around the world (Perrin 2009). It ranges as far south as 40°S in the Pacific Ocean, is common in coastal waters 200–300 m deep and is also associated with prominent underwater topography, such as seamounts

(Evans 1994). Short-beaked common dolphins have been sighted as far as 550 km from shore (Barlow et al. 1997).

The distribution of short-beaked common dolphins along the U.S. west coast is variable and likely related to oceanographic changes (Heyning and Perrin 1994; Forney and Barlow 1998). It is the most abundant cetacean off California; some sightings have been made off Oregon, in offshore waters (Carretta et al. 2017). During surveys off the west coast in 2014 and 2017, sightings were made as far north as 44°N (Barlow 2016; SIO n.d.). Based on the absolute dynamic topography of the region, short-beaked common dolphins could occur in relatively high densities off Oregon during July–December (Pardo et al. 2015). In contrast, habitat modeling predicted moderate densities of common dolphins off the Columbia River mouth during summer, with lower densities off southern Oregon (Becker et al. 2014). There are no sightings of short-beaked dolphins near the proposed survey area in the OBIS database (OBIS 2018). It is possible that short-beaked dolphins could be encountered in the proposed survey area.

3.3.2.10 Striped Dolphin (*Stenella coeruleoalba*)

The striped dolphin has a cosmopolitan distribution in tropical to warm temperate waters (Perrin et al. 1994) and is generally seen south of 43°N (Archer 2009). However, in the eastern North Pacific, its distribution extends as far north as Washington (Jefferson et al. 2015). The striped dolphin is typically found in waters outside the continental shelf and is often associated with convergence zones and areas of upwelling (Archer 2009). However, it has also been observed approaching shore where there is deep water close to the coast (Jefferson et al. 2015).

Striped dolphins regularly occur off California (Becker et al. 2012), where they have been seen as far as the ~300 nmi limit during the NOAA Fisheries vessel surveys (Carretta et al. 2017). Very few sightings have been made off Oregon, and no sightings have been reported for Washington (Carretta et al. 2017). However, strandings have occurred along the coasts of Oregon and Washington (Carretta et al. 2016a). During surveys off the U.S. west coast in 2014, striped dolphins were seen as far north as 44°N; based on those sightings, Barlow (2016) calculated an abundance estimate of 13,171 striped dolphins for the Oregon/Washington region. The abundance estimates for 2001, 2005, and 2008 were zero (Barlow 2016). There are no sightings of striped dolphins near the proposed survey area in the OBIS database (OBIS 2018). It is possible, although unlikely, that striped dolphins could be encountered in the proposed survey area.

3.3.2.11 Pacific White-sided Dolphin (*Lagenorhynchus obliquidens*)

The Pacific white-sided dolphin is found in cool temperate waters of the North Pacific from the southern Gulf of California to Alaska. Across the North Pacific, it appears to have a relatively narrow distribution between 38°N and 47°N (Brownell et al. 1999). In the eastern North Pacific Ocean, including waters off Oregon, the Pacific white-sided dolphin is one of the most common cetacean species, occurring primarily in shelf and slope waters (Green et al. 1993; Barlow 2003, 2010). It is known to occur close to shore in certain regions, including (seasonally) southern California (Brownell et al. 1999).

Results of aerial and shipboard surveys strongly suggest seasonal north–south movements of the species between California and Oregon/Washington; the movements apparently are related to oceanographic influences, particularly water temperature (Green et al. 1993; Forney and Barlow 1998; Buchanan et al. 2001). During winter, this species is most abundant in California slope and offshore areas; as northern waters begin to warm in the spring, it appears to move north to slope and offshore waters off Oregon/Washington (Green et al. 1992, 1993; Forney 1994; Forney et al. 1995; Buchanan et al. 2001; Barlow 2003). The highest encounter rates off Oregon and Washington have been reported during

March–May in slope and offshore waters (Green et al. 1992). Similarly, Becker et al. (2014) predicted relatively high densities off southern Oregon in shelf and slope waters.

Based on year-round aerial surveys off Oregon/Washington, the Pacific white-sided dolphin was the most abundant cetacean species, with nearly all (97%) sightings occurring in May (Green et al. 1992, 1993). Barlow (2003) also found that the Pacific white-sided dolphin was one of the most abundant marine mammal species off Oregon/Washington during 1996 and 2001 ship surveys, and it was the second most abundant species reported during 2008 surveys (Barlow 2010). Adams et al. (2014) reported numerous offshore sightings off Oregon during summer, fall, and winter surveys in 2011 and 2012. Based on surveys conducted during 2014, the abundance was estimated at 20,711 for Oregon/Washington (Barlow 2016).

Fifteen Pacific white-sided dolphin sightings (231 animals) were made off Washington/Oregon during the June–July 2012 L-DEO Juan de Fuca plate seismic survey; none were near the proposed survey area (RPS 2012b). There were fifteen Pacific white-sided dolphin sightings (462 animals) made during the July 2012 L-DEO seismic surveys off southern Washington, northeast of the proposed survey area (RPS 2012a). This species was not sighted during the July 2012 L-DEO seismic survey off Oregon, southeast of the proposed survey area (RPS 2012c). There is one sighting of Pacific white-sided dolphins in the OBIS database that was made in August 2005, ~40 km to the southwest of the survey area during the SWFSC CSCAPE Marine Mammal Survey (OBIS 2018). One group of 10 Pacific white-sided dolphins was sighted during the 2009 ETOMO survey north of the proposed survey area (Holst 2017). Pacific white-sided dolphins are likely to be common in the proposed survey area.

3.3.2.12 Northern Right Whale Dolphin (*Lissodelphis borealis*)

The northern right whale dolphin is found in cool temperate and sub-arctic waters of the North Pacific, from the Gulf of Alaska to near northern Baja California, ranging from 30°N to 50°N (Reeves et al. 2002). In the eastern North Pacific Ocean, including waters off Oregon, the northern right whale dolphin is one of the most common marine mammal species, occurring primarily in shelf and slope waters ~100 to >2000 m deep (Green et al. 1993; Barlow 2003). The northern right whale dolphin comes closer to shore where there is deep water, such as over submarine canyons (Reeves et al. 2002).

Aerial and shipboard surveys suggest seasonal inshore–offshore and north–south movements in the eastern North Pacific Ocean between California and Oregon/Washington; the movements are believed to be related to oceanographic influences, particularly water temperature and presumably prey distribution and availability (Green et al. 1993; Forney and Barlow 1998; Buchanan et al. 2001). Green et al. (1992, 1993) found that northern right whale dolphins were most abundant off Oregon/Washington during fall, less abundant during spring and summer, and absent during winter, when this species presumably moves south to warmer California waters (Green et al. 1992, 1993; Forney 1994; Forney et al. 1995; Buchanan et al. 2001; Barlow 2003). Considerable interannual variations in abundance also have been found.

Becker et al. (2014) predicted relatively high densities off southern Oregon, and moderate densities off northern Oregon and Washington. Based on year-round aerial surveys off Oregon/Washington, the northern right whale dolphin was the third most abundant cetacean species, concentrated in slope waters but also occurring in water out to ~550 km offshore (Green et al. 1992, 1993). Barlow (2003, 2010) also found that the northern right whale dolphin was one of the most abundant marine mammal species off Oregon/Washington during 1996, 2001, 2005, and 2008 ship surveys. Offshore sightings were made in the waters of Oregon during summer, fall, and winter surveys in 2011 and 2012 (Adams et al. 2014).

Seven northern right whale dolphin sightings (231 animals) were made off Washington/Oregon during the June–July 2012 L-DEO Juan de Fuca plate seismic survey; none were seen near the proposed survey area (RPS 2012b). There were eight northern right whale dolphin sightings (278 animals) made during the July 2012 L-DEO seismic surveys off southern Washington, northeast of the proposed survey area (RPS 2012a). This species was not sighted during the July 2012 L-DEO seismic survey off Oregon, southeast of the proposed survey area (RPS 2012c). There is one sighting of northern right whale dolphins in the OBIS database that was made during August 2001 ~40 km to the south of the survey area during the SWFSC ORCAWALE Marine Mammal Survey (OBIS 2018). Northern right whale dolphins are likely to be encountered in the proposed survey area.

3.3.2.13 Risso's Dolphin (*Grampus griseus*)

Risso's dolphin is distributed worldwide in temperate and tropical oceans (Baird 2009), although it shows a preference for mid-temperate waters of the shelf and slope between 30° and 45° (Jefferson et al. 2014). Although it is known to occur in coastal and oceanic habitats (Jefferson et al. 2014), it appears to prefer steep sections of the continental shelf, 400–1000 m deep (Baird 2009), and is known to frequent seamounts and escarpments (Kruse et al. 1999). Off the U.S. west coast, Risso's dolphin is believed to make seasonal north-south movements related to water temperature, spending colder winter months off California and moving north to waters off Oregon/Washington during the spring and summer as northern waters begin to warm (Green et al. 1992, 1993; Buchanan et al. 2001; Barlow 2003; Becker 2007).

The distribution and abundance of Risso's dolphins are highly variable from California to Washington, presumably in response to changing oceanographic conditions on both annual and seasonal time scales (Forney and Barlow 1998; Buchanan et al. 2001). The highest densities were predicted along the coasts of Washington, Oregon, and central and southern California (Becker et al. 2012). Off Oregon and Washington, Risso's dolphins are most abundant over continental slope and shelf waters during spring and summer, less so during fall, and rare during winter (Green et al. 1992, 1993). Green et al. (1992, 1993) reported most Risso's dolphin groups off Oregon between ~45 and 47°N. Several sightings were made off southern Oregon during surveys in 1991–2014 (Carretta et al. 2017). Sightings during ship surveys in summer/fall 2008 were mostly between ~30 and 38°N; none were reported in Oregon/Washington (Barlow 2010). Based on 2014 survey data, the abundance for Oregon/Washington was estimated at 430 (Barlow 2016)

Two sightings of 38 individuals were recorded off Washington from August 2004 to September 2008 (Oleson et al. 2009). Risso's dolphins were sighted off Oregon, in June and October 2011 (Adams et al. 2014). There were three Risso's dolphin sightings (31 animals) made during the July 2012 L-DEO seismic surveys off southern Washington, northeast of the proposed survey area (RPS 2012a). This species was not sighted during the July 2012 L-DEO seismic survey off Oregon, southeast of the proposed survey area (RPS 2012c), or off Washington/Oregon during the June–July 2012 L-DEO Juan de Fuca plate seismic survey (RPS 2012b). There is one sighting of Risso's dolphins in the OBIS database that was made in July 1996 ~35 km to the northeast of the survey area during the SWFSC ORCAWALE Marine Mammal Survey (OBIS 2018). Risso's dolphins could be encountered in the proposed survey area.

3.3.2.14 False Killer Whale (*Pseudorca crassidens*)

The false killer whale is found in all tropical and warmer temperate oceans, especially in deep, offshore waters (Odell and McClune 1999). However, it is also known to occur in nearshore areas (e.g., Stacey and Baird 1991). In the eastern North Pacific, it has been reported only rarely north of Baja California (Leatherwood et al. 1982, 1987; Mangels and Gerrodette 1994); however, the waters off the

U.S. west coast all the way north to Alaska are considered part of its secondary range (Jefferson et al. 2015). Its occurrence in Washington/Oregon is associated with warm-water incursions (Buchanan et al. 2001). However, no sightings of false killer whales were made along the U.S. west coast during surveys conducted from 1986 to 2001 (Ferguson and Barlow 2001, 2003; Barlow 2003) or in 2005 and 2008 (Forney 2007; Barlow 2010). One pod of false killer whales occurred in Puget Sound for several months during the 1990s (USN 2015). Two were reported stranded along the Washington coast during 1930–2002, both in El Niño years (Norman et al. 2004). One sighting was made of southern California during 2014 (Barlow 2016). There are no sightings of false killer whales near the survey area in the OBIS database (OBIS 2018). This species is unlikely to be encountered during the proposed survey.

3.3.2.15 Killer Whale (*Orcinus orca*)

The killer whale is cosmopolitan and globally fairly abundant; it has been observed in all oceans of the world (Ford 2009). It is very common in temperate waters and also frequents tropical waters, at least seasonally (Heyning and Dahlheim 1988). Currently, there are eight killer whale stocks recognized in the Pacific U.S.: (1) Alaska Residents, occurring from southeast Alaska to the Aleutians and Bering Sea; (2) Northern Residents, from BC through parts of southeast Alaska; (3) Southern Residents, mainly in inland waters of Washington State and southern BC; (4) Gulf of Alaska, Aleutians, and Bering Sea Transients, from Prince William Sound (PWS) through to the Aleutians and Bering Sea; (5) AT1 Transients, from PWS through the Kenai Fjords; (6) West Coast Transients, from California through southeast Alaska; (7) Offshore, from California through Alaska; and (8) Hawaiian (Carretta et al. 2018). Individuals from the Offshore and West Coast Transient stocks could be encountered in the proposed project area.

Green et al. (1992) noted that most groups seen during their surveys off Oregon and Washington were likely transients; during those surveys, killer whales were sighted only in shelf waters. Eleven sightings of ~536 individuals were reported off Oregon/Washington during the 2008 SWFSC vessel survey (Barlow 2010). Killer whales were sighted offshore Washington during surveys from August 2004 to September 2008 (Oleson et al. 2009). Keating et al. (2015) analysed cetacean whistles from recordings made during 2000–2012; several killer whale acoustic detections were made offshore Washington. Killer whales were sighted off Washington in July and September 2012 (Adams et al. 2014). Two of 17 killer whales that stranded in Oregon were confirmed as transient (Stevens et al. 1989 in Norman et al. 2004). There are no sightings of killer whales near the proposed survey area in the OBIS database (OBIS (2018). However, killer whales could be encountered during the proposed survey.

3.3.2.16 Short-finned Pilot Whale (*Globicephala macrorhynchus*)

The short-finned pilot whale is found in tropical, subtropical, and warm temperate waters (Olson 2009); it is seen as far south as ~40°S and as far north as ~50°N (Jefferson et al. 2015). Pilot whales are generally nomadic, but may be resident in certain locations, including California and Hawaii (Olson 2009). Short-finned pilot whales were common off southern California (Dohl et al. 1980) until an El Niño event occurred in 1982–1983 (Carretta et al. 2017). Few sightings were made off California/Oregon/Washington in 1984–1992 (Green et al. 1992; Carretta and Forney 1993; Barlow 1997), and sightings remain rare (Barlow 1997; Buchanan et al. 2001; Barlow 2010). No short-finned pilot whales were seen during surveys off Oregon and Washington in 1989–1990, 1992, 1996, and 2001 (Barlow 2003). A few sightings were made off California during surveys in 1991–2014 (Barlow 2010). Carretta et al. (2017) reported one sighting off Oregon during 1991–2008. Several stranding events in Oregon/southern Washington have been recorded over the past few decades, including in March 1996, June 1998, and August 2002 (Norman et al. 2004). There are no sightings of short-finned whales near the

proposed survey area in the OBIS database (OBIS (2018)). This species is unlikely to be encountered in the proposed survey area.

3.3.2.17 Dall's Porpoise (*Phocoenoides dalli*)

Dall's porpoise is found in temperate to subantarctic waters of the North Pacific and adjacent seas (Jefferson et al. 2015). It is widely distributed across the North Pacific over the continental shelf and slope waters, and over deep (>2500 m) oceanic waters (Hall 1979). It is probably the most abundant small cetacean in the North Pacific Ocean, and its abundance changes seasonally, likely in relation to water temperature (Becker 2007).

Off Oregon and Washington, Dall's porpoise is widely distributed over shelf and slope waters, with concentrations near shelf edges, but is also commonly sighted in pelagic offshore waters (Morejohn 1979; Green et al. 1992; Becker et al. 2014; Carretta et al. 2018). Combined results of various surveys out to ~550 km offshore indicate that the distribution and abundance of Dall's porpoise varies between seasons and years. North-south movements are believed to occur between Oregon/Washington and California in response to changing oceanographic conditions, particularly temperature and distribution and abundance of prey (Green et al. 1992, 1993; Mangels and Gerrodette 1994; Barlow 1995; Forney and Barlow 1998; Buchanan et al. 2001). Becker et al. (2014) predicted high densities off southern Oregon throughout the year, with moderate densities to the north. According to predictive density distribution maps, the highest densities off southern Washington and Oregon occur along the 500-m isobath (Menza et al. 2016).

Encounter rates reported by Green et al. (1992) during aerial surveys off Oregon/Washington were highest in fall, lowest during winter, and intermediate during spring and summer. Encounter rates during the summer were similarly high in slope and shelf waters, and somewhat lower in offshore waters (Green et al. 1992). Dall's porpoise was the most abundant species sighted off Oregon/Washington during 1996, 2001, 2005, and 2008 ship surveys up to ~550 km from shore (Barlow 2003, 2010). Oleson et al. (2009) reported 44 sightings of 206 individuals off Washington during surveys from August 2004 to September 2008. Dall's porpoise were seen in the waters off Oregon during summer, fall, and winter surveys in 2011 and 2012 (Adams et al. 2014).

Nineteen Dall's porpoise sightings (144 animals) were made off Washington/Oregon during the June-July 2012 L-DEO Juan de Fuca plate seismic survey; none were in near the proposed survey area (RPS 2012b). There were 16 Dall's porpoise sightings (54 animals) made during the July 2012 L-DEO seismic surveys off southern Washington, northeast of the proposed survey area (RPS 2012a). This species was not sighted during the July 2012 L-DEO seismic survey off Oregon, southeast of the proposed survey area (RPS 2012c). There are five sightings of Dall's porpoises near the proposed survey area in the OBIS database that were made in July and August of 1996, 2001, and 2008 during SWFSC marine mammal surveys (OBIS 2018). Dall's porpoise was the most frequently sighted marine mammal species (5 sightings or 28 animals) during the 2009 ETOMO survey north of the proposed survey area (Holst 2017). This species is likely to be encountered during the proposed seismic survey.

3.3.3 Pinnipeds

3.3.3.1 Northern Fur Seal (*Callorhinus ursinus*)

The northern fur seal is endemic to the North Pacific Ocean and occurs from southern California to the Bering Sea, Sea of Okhotsk, and Sea of Japan (Jefferson et al. 2015). The worldwide population of northern fur seals has declined substantially from 1.8 million animals in the 1950s (Muto et al. 2018). They were subjected to large-scale harvests on the Pribilof Islands to supply a lucrative fur trade. Two stocks are recognized in U.S. waters: the Eastern North Pacific and the California stocks. The Eastern

Pacific stock ranges from southern California during winter to the Pribilof Islands and Bogoslof Island in the Bering Sea during summer (Carretta et al. 2018; Muto et al. 2018). Abundance of the Eastern Pacific Stock has been decreasing at the Pribilof Islands since the 1940s and increasing on Bogoslof Island.

Most northern fur seals are highly migratory. During the breeding season, most of the world's population of northern fur seals occurs on the Pribilof and Bogoslof islands (NMFS 2007). The main breeding season is in July (Gentry 2009). Adult males usually occur onshore from May to August, though some may be present until November; females are usually found ashore from June to November (Muto et al. 2018). Nearly all fur seals from the Pribilof Island rookeries are foraging at sea from fall through late spring. In November, females and pups leave the Pribilof Islands and migrate through the Gulf of Alaska to feeding areas primarily off the coasts of BC, Washington, Oregon, and California before migrating north again to the rookeries in spring (Ream et al. 2005; Pelland et al. 2014). Immature seals can remain in southern foraging areas year-round until they are old enough to mate (NMFS 2007). Adult males migrate only as far south as the Gulf of Alaska or to the west off the Kuril Islands (Kajimura 1984). Pups from the California stock also migrate to Washington, Oregon, and northern California after weaning (Lea et al. 2009).

The northern fur seals spends ~90% of its time at sea, typically in areas of upwelling along the continental slopes and over seamounts (Gentry 1981). The remainder of its life is spent on or near rookery islands or haulouts. While at sea, northern fur seals usually occur singly or in pairs, although larger groups can form in waters rich with prey (Antonelis and Fiscus 1980; Gentry 1981). Northern fur seals dive to relatively shallow depths to feed: 100–200 m for females, and <400 m for males (Gentry 2009). Tagged adult female fur seals were shown to remain within 200 km of the shelf break (Pelland et al. 2014).

Bonnell et al. (1992) noted the presence of northern fur seals year-round off Oregon/Washington, with the greatest numbers (87%) occurring in January–May. Northern fur seals were seen as far out from the coast as 185 km, and numbers increased with distance from land; they were 5–6 times more abundant in offshore waters than over the shelf or slope (Bonnell et al. 1992). The highest densities were seen in the Columbia River plume (~46°N) and in deep offshore waters (>2000 m) off central and southern Oregon (Bonnell et al. 1992). The waters off Washington are a known foraging area for adult females, and concentrations of fur seals were also reported to occur near Cape Blanco, Oregon, at ~42.8°N (Pelland et al. 2014). Tagged adult fur seals were tracked from the Pribilof Islands to the waters off Washington/Oregon/California, with recorded movement throughout the proposed project area (Pelland et al. 2014).

Thirty-one northern fur seal sightings (63 animals) were made off Washington/Oregon during the June–July 2012 L-DEO Juan de Fuca plate seismic survey north of the proposed survey area (RPS 2012b). There were six sightings (6 animals) made during the July 2012 L-DEO seismic surveys off southern Washington, northeast of the proposed survey area (RPS 2012a). This species was not sighted during the July 2012 L-DEO seismic survey off Oregon, southeast of the proposed survey area (RPS 2012c). There are no sightings of northern fur seals near the proposed survey area in the OBIS database (OBIS 2018). Northern fur seals could be observed in the proposed survey area, though adult males are generally ashore during the reproductive season from May to August, and adult females are generally ashore from June through November.

3.3.3.2 Guadalupe Fur Seal (*Arctocephalus townsendi*)

Most breeding and births occur at Isla Guadalupe, Mexico; a secondary rookery exists at Isla Benito del Este (Maravilla-Chavez and Lowry 1999; Auriolos-Gamboa et al. 2010). A few Guadalupe fur

seals are known to occur at California sea lion rookeries in the Channel Islands, primarily San Nicolas and San Miguel islands, and sightings have also been made at Santa Barbara and San Clemente islands (Stewart et al. 1987; Carretta et al. 2017). Guadalupe fur seals prefer rocky habitat for breeding and hauling out. They generally haul out at the base of towering cliffs on shores characterized by solid rock and large lava blocks (Peterson et al. 1968), although they can also inhabit caves and recesses (Belcher and Lee 2002). While at sea, this species usually is solitary but typically gathers in the hundreds to thousands at breeding sites.

During the summer breeding season, most adults occur at rookeries in Mexico (Carretta et al. 2017; Norris 2017 *in* USN 2018). Following breeding season, adult males tend to move northward to forage. Females have been observed feeding south of Guadalupe Island, making an average round trip of 2375 km (Ronald and Gots 2003). Several rehabilitated Guadalupe fur seals that were satellite tagged and released in central California traveled as far north as BC (Norris et al. 2015; Norris 2017 *in* USN 2018). Fur seals younger than two years old are more likely to travel to more northerly, offshore areas than older fur seals (Norris 2017 *in* USN 2018). Stranding data also indicates that fur seals younger than 2 years are more likely to occur in the proposed survey area, as this age class was more commonly reported off the coast of BC (Lambourn et al. 2012 *in* USN 2018). In 2015–2016, 175 Guadalupe fur seals stranded on the coast of California; NMFS declared this an unusual mortality event (Carretta et al. 2017).

There are no sightings of Guadalupe fur seals in the OBIS database near the proposed survey area and surrounding waters (OBIS 2018).

3.3.3.3 Northern Elephant Seal (*Mirounga angustirostris*)

The northern elephant seal breeds in California and Baja California, primarily on offshore islands, from Cedros off the west coast of Baja California, north to the Farallons in Central California (Stewart et al. 1994). Pupping has also been observed at Shell Island (~43.3°N) off southern Oregon, suggesting a range expansion (Bonnell et al. 1992; Hodder et al. 1998).

Adult elephant seals engage in two long northward migrations per year, one following the breeding season, and another following the annual molt (Stewart and DeLong 1995). Between the two foraging periods, they return to land to molt, with females returning earlier than males (March–April vs. July–August). After the molt, adults then return to their northern feeding areas until the next winter breeding season. Breeding occurs from December to March (Stewart and Huber 1993). Females arrive in late December or January and give birth within ~1 week of their arrival. Pups are weaned after just 27 days and are abandoned by their mothers. Juvenile elephant seals typically leave the rookeries in April or May and head north, traveling an average of 900–1000 km. Hindell (2009) noted that traveling likely takes place at depths >200 m. Most elephant seals return to their natal rookeries when they start breeding (Huber et al. 1991).

When not at their breeding rookeries, adults feed at sea far from the rookeries. Males may feed as far north as the eastern Aleutian Islands and the Gulf of Alaska, whereas females feed south of 45°N (Le Boeuf et al. 1993; Stewart and Huber 1993). Adult male elephant seals migrate north via the California current to the Gulf of Alaska during foraging trips, and could potentially be passing through the area off Washington in May and August (migrating to and from molting periods) and November and February (migrating to and from breeding periods), but likely their presence there is transient and short-lived. Adult females and juveniles forage in the California current off California to BC (Le Boeuf et al. 1986, 1993, 2000). Bonnell et al. (1992) reported that northern elephant seals were distributed equally in shelf, slope, and offshore waters during surveys conducted off Oregon and Washington, as far as 150 km from shore, in waters >2000 m deep. Telemetry data indicate that they range much farther

offshore than that (Stewart and DeLong 1995).

Off Washington, most elephant seal sightings at sea were made during June, July, and September; off Oregon, sightings were recorded from November through May (Bonnell et al. 1992). Several seals were seen off Oregon during summer, fall, and winter surveys in 2011 and 2012 (Adams et al. 2014). Northern elephant seals were also taken as bycatch off Oregon in the west coast groundfish fishery during 2002–2009 (Jannot et al. 2011). Northern elephant seals were sighted five times (5 animals) during the July 2012 L-DEO seismic surveys off southern Washington, northeast of the proposed survey area (RPS 2012a). This species was not sighted during the July 2012 L-DEO seismic survey off Oregon, southeast of the proposed survey area (RPS 2012c), or off Washington/Oregon during the June–July 2012 L-DEO Juan de Fuca plate seismic survey that included the proposed survey area (RPS 2012b). There are several sightings of northern elephant seals in the OBIS database near the proposed survey area and surrounding waters (OBIS 2018). One northern elephant seal was sighted during the 2009 ETOMO survey north of the proposed survey area (Holst 2017). This species could be encountered during the proposed seismic survey.

3.4 Sea Turtles

Since 1985, four species of sea turtles have been documented off the coasts of Oregon and/or Washington: the leatherback (*Dermochelys coriacea*), loggerhead (*Caretta caretta*), green (*Chelonia mydas*), and olive ridley (*Lepidochelys olivacea*) turtles (Green et al. 1992; Bowlby et al. 1994; Buchanan et al. 2001). Under the ESA, the leatherback turtle and the North Pacific Ocean DPS of the loggerhead turtle are listed as **endangered**, the olive ridley population on the Pacific coast of Mexico is listed as **endangered** whereas other populations are listed as **threatened**, and the East Pacific DPS of the green turtle is listed as **threatened**. Under the IUCN Red List (IUCN 2018), the hawksbill turtle is listed as **critically endangered**, the green turtle is listed as **endangered**, and the leatherback, olive ridley, and loggerhead turtles are listed as **vulnerable**.

The leatherback turtle is the only sea turtle likely to occur in the waters of the proposed project area. The other three species have been documented off the coasts of Oregon or Washington as strandings and are considered extralimital occurrences of those generally warm-water species (Bowlby et al. 1994; Buchanan et al. 2001). Strandings have increased in recent years, particularly for olive ridley sea turtles, possibly due to warmer ocean conditions or El Niño (Boyer 2017). However, green, loggerhead, and olive ridley sea turtles are still considered accidental in Oregon (OFWC 2013). Those three species are not addressed further here.

General information on the taxonomy, ecology, distribution and movements, and acoustic capabilities of sea turtles are given in § 3.4.1 of the PEIS. General distribution of sea turtles off Southern California and B.C. are discussed in § 3.4.2.3 and § 3.4.3.2, respectively. The rest of this section deals specifically with their distribution within the proposed survey area in the Northeast Pacific.

3.4.1 Leatherback Turtle (*Dermochelys coriacea*)

The leatherback is the largest and most widely distributed sea turtle, ranging far from its tropical and subtropical breeding grounds to feed (Plotkin 2003). The leatherback turtle is listed as **endangered** under the ESA and is listed in CITES Appendix I (UNEP-WCMC 2018). Globally, the leatherback turtle is designated as **vulnerable** on the IUCN Red List of Threatened Species, but the East Pacific Ocean and West Pacific Ocean subpopulations are considered **critically endangered** (IUCN 2018). There have been significant declines and some extirpations of nesting populations in the Pacific (Spotila et al. 2000; Dutton et al. 2007). Nesting beaches in the western Pacific have 2700–4500 breeding females

(NMFS and USFWS 2013).

The largest remaining nesting sites for leatherbacks in the Pacific Ocean occur on the beaches of Birdshead Peninsula in Papua, Indonesia (Dutton et al. 2007; Hitipeuw et al. 2007; Benson et al. 2008). In the western Pacific, leatherbacks also nest in New Guinea, the Solomon Islands, and Vanuatu, with fewer nesting in Fiji, Malaysia, and Australia (NMFS and USFWS 2013). Nesting leatherbacks have also been discovered in Japan (Kamezaki et al. 2002). In the eastern Pacific, leatherbacks nest along the west coast of Mexico and Central America (Marquez 1990).

Leatherbacks are highly migratory and feed in areas of high productivity, such as convergence zones, and upwelling areas in the open ocean, along continental margins, and in archipelagic waters (Morreale et al. 1994; Eckert 1995). Adult leatherbacks appear to migrate along bathymetric contours from 200 to 3500 m (Morreale et al. 1994). Adults spend the majority of their time in water >1000 m deep and possibly swim more than 10,000 km each year (Eckert 1995). They appear to use the Kuroshio Extension during migrations from Indonesia to the high seas and eastern Pacific (Benson et al. 2008). Frair et al. (1972) and Greer et al. (1973) reported that leatherback turtles have evolved physiological and anatomical adaptations to cold water, allowing them to venture into higher latitudes than other species of turtle.

Hatchling leatherbacks are pelagic, but nothing is known about their distribution for the first four years (Musick and Limpus 1997). Leatherback turtles undertake long migrations from the western, central, or South Pacific toward the California Current Large Marine Ecosystem (Block et al. 2011; Bailey et al. 2012). After analyzing some 363 records of sea turtles sighted along the Pacific coast of North America, Stinson (1984) concluded that the leatherback was the most common sea turtle in U.S. waters north of Mexico. Roe et al. (2014) also predicted high densities off the northwest coast of the U.S. from July–December. Sightings and incidental capture data indicate that leatherbacks are found as far north as 60°N, and documented encounters extend southward through the waters of BC, Washington, Oregon, and California (Green et al. 1992; Bowlby et al. 1994; NMFS and USFWS 1998). Leatherbacks occur north of central California during the summer and fall, when sea surface temperatures are highest (Dohl et al. 1983; Brueggeman 1991). Some aerial surveys of California, Oregon, and Washington waters suggest that most leatherbacks occur in continental slope waters and fewer occur over the continental shelf. Satellite tracking has shown that leatherbacks from the western Pacific population travel to Washington and Oregon waters to feed in continental shelf and slope waters, particularly near the Columbia River Plume; individuals occurred in the area from July through December, passing to the south of the proposed survey area (Benson et al. 2011).

In the Pacific Ocean, designated critical habitat includes ~108,600 km² of marine habitat off the U.S. west coast, including an area stretching along the California coast, and an area stretching from Cape Flattery, Washington, to Cape Blanco, Oregon, east of a line approximating the 2000-m depth contour. The proposed offshore survey area is located well to the west of the critical habitat. There are no observations of this species in the OBIS database for the proposed survey area (OBIS 2018). One leatherback sea turtle was sighted during the 2009 ETOMO survey north of the proposed survey area (Holst 2017). Leatherback sea turtles could occur in the proposed survey area.

3.5 Seabirds

Three seabird species that are listed under the ESA could occur in or near the proposed survey area. The *endangered* short-tailed albatross (*Phoebastria albatrus*) and Hawaiian petrel (*Pterodroma sandwichensis*) could be present as seasonal visitors to the project area. The *threatened* western snowy

plover (*Charadrius alexandrinus nivosus*) and the **threatened** marbled murrelet (*Brachyramphus marmoratus*) are coastal species and would not be encountered offshore.

3.5.1 Short-tailed Albatross

Historically, millions of short-tailed albatrosses bred in the western North Pacific on islands off the coast of Japan (USFWS 2008). This species was the most abundant albatross in the North Pacific. However, the entire global population was nearly wiped out during the last century by feather hunters at Japanese breeding colonies. In addition to hunting pressures, the breeding grounds of the remaining birds were threatened by volcanic eruptions in the 1930s. This species was believed to be extinct by 1949; however, breeding was detected in 1950 and 1951, aided by pelagic-dwelling maturing birds which escaped the slaughter (USFWS 2008; BirdLife International 2018a). Due to conservation and management actions the population is increasing, and the most recent population estimate is 4200 individuals (BirdLife International 2018a). Current threats to this population include volcanic activity on Torishima, commercial fisheries, and pollutants (USFWS 2008). Interactions with vessels in the eastern Pacific have been noted. Incidental take due to commercial fisheries has been documented, with one short-tailed albatross taken as bycatch off Oregon during the sablefish demersal fishery in 2011 (USFWS 2017), and 11 mortalities between 1995 and 2015 in the Alaska hook-and-line groundfish fishery (NMFS 2015a; USFWS 2017).

Currently, nearly all short-tailed albatrosses breed on two islands off the coast of Japan: Torishima and Minami-kojima (USFWS 2008; BirdLife International 2018a). Single nests have been found in recent years on other islands, including Kita-Kojima, Senkaku; Yomejima Island; and Midway Island, Hawaii; however, nesting attempts in Hawaii have not been successful (USFWS 2008). During the breeding season (December–May), the highest densities are found around Japan (BirdLife International 2018a), with albatross being seen as far south (23°N) as the Northwestern Hawaiian Islands between November and April (USFWS 2008).

During the non-breeding season, short-tailed albatrosses roam much of the North Pacific Ocean; females spend more time offshore from Japan and Russia, whereas males and juveniles spend more time around the Aleutian Islands and Bering Sea (Suryan et al. 2007). Post-breeding dispersal occurs from April through August (USFWS 2008). After leaving the breeding areas, short-tailed albatrosses seem to spend the majority of time within the EEZs of Japan, Russia, and the U.S., primarily in the Aleutian Islands and Bering Sea (Suryan et al. 2007). They are considered a continental shelf-edge specialist (Piatt et al. 2006). Most of the short-tailed albatrosses sighted off the Pacific Coast of North America (south to California) are juveniles and sub-adults (USFWS 2008; O'Connor 2013). Satellite-tracked first and second year birds were found in Oregon waters most often during winter and spring, possibly in response to ice conditions in the Bering Sea (O'Connor 2013). Sightings in the eastern North Pacific are increasing, corresponding with global population increases (COSEWIC 2013). The short-tailed albatross could be encountered in very small numbers in the proposed project area.

3.5.2 Hawaii Petrel

The Hawaiian petrel has an estimated population size of 6000–11,000 (BirdLife International 2018b). Large declines in overall numbers and in the number of breeding colonies appear to pre-date European arrival on the Hawaiian Islands, tracing back to animal introductions, habitat modifications, and hunting by Polynesians (Simons and Hodges 1998). The population of Hawaiian petrels continues to decline, mainly because of predation by introduced vertebrates, including mongooses, cats, and goats, and due to collisions and light attraction (Raine et al. 2017; USFWS 2005).

The Hawaiian petrel is endemic to Hawaii, where it nests at high elevation. Known nesting habitats include lava cavities, burrows on cliff faces or steep slopes, and beneath ferns (USFWS 2005). The majority of eggs are laid in May and June, and most young fledge in December (Mitchell et al. 2005). Hawaiian petrels can travel up to 1300 km away from colonies during foraging trips; at-sea densities decrease with distance from the colony (Spear et al. 1995). Spear et al. (1995) showed the distribution of Hawaiian petrels to be concentrated in the southern portion of the Main Hawaiian Islands (below 20°N) during spring and autumn. However, in recent years, the Hawaiian Petrel has been recognized to be a regularly occurring offshore species to the eastern Pacific in waters from southern California to southern BC. In California, where observer coverage is perhaps highest, there are records from March through September (eBird 2018). There are two accepted records of Hawaiian Petrel in Washington (September 2008 and May 2014; WBRC 2018) and three in BC (July 2013, May 2014, and July 2014; BCBRC 2018), although occurrences are likely more frequent than observations suggest owing to the minimal observer coverage at the distance from shore which these petrels typically frequent. The Hawaiian Petrel could be encountered in very small numbers in the proposed project area.

3.6 ESA-listed Fish, Essential Fish Habitat, and Habitat Areas of Particular Concern

The term “species” under the ESA includes species, subspecies, and, for vertebrates only, DPSs or “evolutionarily significant units (ESUs)”; for Pacific salmon, ESUs are essentially equivalent to DPSs for the purpose of the ESA. There are several ESA-listed fish species or populations that occur off the coasts of Washington and Oregon including the ESUs of chinook, chum, coho, and sockeye salmon, and the DPSs of bocaccio, yellow rockfish, Pacific eulachon, steelhead, and green sturgeon (Table 6). Although the *threatened* giant manta ray (*Manta birostris*) and oceanic whitetrip shark (*Carcharhinus longimanus*), and the *endangered* Eastern Pacific DPS of scalloped hammerhead shark (*Sphyrna lewini*) occur in the Northeast Pacific Ocean, their most northerly extent is California; these species are not considered further.

Based on available information, salmon, steelhead trout, and larvae and pelagic juvenile bocaccio could potentially occur in the project area, whereas yelloweye rockfish, Pacific eulachon/smelt, green sturgeon, and adult bocaccio likely would not (Light et al. 1989; DFO 2018b; NMFS 2014, 2017a, 2018d). Pacific salmon and steelhead trout typically spend the majority of their time in the upper water column while at sea (e.g., Daly et al. 2014; PFMC 2014). However, Chinook typically occur at depths >30 m from the sea surface (PFMC 2014). The degree to which Pacific salmon and steelhead migrate offshore varies considerably among seasons, years, life stages and/or populations, with stronger upwelling conditions generally leading to wider dispersal from shore (Pearcy 1992). Tag recoveries from high seas fisheries indicate that chinook occur beyond the shelf break (Myers et al. 1996). Once coho salmon emigrate from freshwater, they spend at least several weeks and up to a summer season in coastal waters before migrating north and offshore (PFMC 2014). Tag recoveries from fisheries indicate that coho are distributed as far west as 175°E (Myers et al. 1996). However, the oceanic distribution of chum salmon is likely the broadest of any Pacific salmon species; it occurs throughout the North Pacific Ocean north of Oregon/Washington (Neave et al. 1976). Sockeye are thought to follow a similar migration pattern as chum once they enter the ocean, moving north and west along the coast before moving offshore (Quinn 2005; Byron and Burke 2014). Sockeye primarily occur east of 160°W and north of 48°N; most fish likely depart offshore waters by early August of their second at-sea year to spawn in their natal rivers (French et al. 1976). Steelhead appear to rely on offshore waters for feeding than any other Pacific salmonids, making more extensive migrations offshore in their first year (Quinn and Myers 2004). Light et al. (1989) found that steelhead is distributed throughout the North Pacific year-round, occurring in

TABLE 6. Fish “species” listed under the ESA off the coasts of Washington and Oregon (NOAA 2018b)

Species	ESU or DPS	Status	Critical Habitat
Bocaccio	Puget Sound/Georgia Basin DPS*	Endangered	Marine
Yelloweye Rockfish	Puget Sound/Georgia Basin DPS	Threatened	Marine
Pacific eulachon/smelt	Southern DPS	Threatened	Freshwater/estuarine
Green sturgeon	Southern DPS	Threatened	Marine/freshwater/estuarine
Chinook salmon	Upper Columbia River spring-run*	Endangered	Freshwater
	Lower Columbia River*	Threatened	Freshwater
	Puget Sound*	Threatened	Freshwater/marine
	Snake River fall-run*	Threatened	Freshwater
	Snake River spring/summer-run*	Threatened	—
	Upper Willamette River*	Threatened	Freshwater
	Columbia River*	Threatened	Freshwater
Chum salmon	Hood Canal summer-run*	Threatened	Freshwater/marine
	Lower Columbia River*	Threatened	Freshwater
Coho salmon	Oregon coast*	Threatened	Freshwater
	S. Oregon and N. California coasts*	Threatened	—
	Ozette Lake*	Threatened	Freshwater
Sockeye salmon	Snake River*	Endangered	—
	Lower Columbia River DPS*	Threatened	Freshwater
Steelhead trout	Middle Columbia River DPS*	Threatened	Freshwater
	Pudget Sound DPS*	Threatened	Freshwater
	Snake River Basin DPS*	Threatened	Freshwater
	Upper Columbia River DPS*	Threatened	Freshwater
	Upper Willamette River DPS*	Threatened	Freshwater

* Could potentially occur in the proposed survey area.

higher abundance closer to the coasts during spring and winter and being distributed more evenly during summer and autumn. Larval and pelagic juvenile bocaccio tend to occur within surficial waters and have been found as far as 480 km offshore the western US (NMFS 2014).

Critical habitat for salmon and steelhead is in freshwater (and nearshore marine waters for the chinook salmon Puget Sound and chum salmon Hood Canal summer-run DPSs), whereas critical habitat for green sturgeon includes freshwater and coastal bays, estuaries, and marine waters <110 m deep off California, Oregon, and Washington (NOAA 2018b). Critical habitat for bocaccio and yellow rockfish includes nearshore and/or deepwater marine habitats near the Canada-U.S. border off northwestern Washington (NOAA 2018b). Listed critical habitat for the Pacific eulachon includes freshwater and estuarine waters for spawning. Nearshore and offshore foraging habitat are not considered critical habitat for this species (NOAA 2018b).

Under the 1976 *Magnuson Fisheries Conservation and Management Act* (renamed *Magnuson Stevens Fisheries Conservation and Management Act* in 1996), Essential Fish Habitat (EFH) is defined as “those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity”. “Waters” include aquatic areas and their associated physical, chemical, and biological properties that are used by fish. “Substrate” includes sediment, hard bottom, structures underlying the waters, and associated biological communities (NOAA 2018c). Habitat Areas of Particular Concern (HAPCs) are a subset of EFH that provide important ecological functions, are especially vulnerable to degradation, or include habitat that is rare (NOAA 2018d). EFH has been designated for groundfish and pelagic species (or species assemblages), salmonids, and invertebrates in different stages of development. However, there is no EFH or HAPC in the proposed offshore survey area in International Waters. The nearest EFHs

to the proposed survey area are within the western U.S. EEZ off the Washington and Oregon coasts, located east of the survey area. The Thompson Seamount, located ~70 km east of the study area at 46°3'N and 128°35'W, is designated as HAPC. It has an area of ~430 km² and is closed to all bottom contact gear (Oren and DeVogelaere 2014).

3.7 Fisheries

During the most recent years with available data (2006, 2007, 2010, 2014), the total combined commercial landings catch weight within the Northeast Pacific high seas area was 362 mt, predominantly consisting of unspecific pelagic species (95% of total catch weight), unspecified marine fishes (5%), sharks, rays, and skates (0.2%), and albacore tuna (0.2%) (SAU 2016). Other species harvested during this period which each accounted for <0.1% of total catch weight include blue, mako, and thresher sharks; swordfish, bigeye, yellowfin, skipjack, and unspecified tunas; billfishes; mackerels; and bonitos (SAU 2016). The majority of catch was harvested using unknown (87%) and 'mixed' (12%) gear types, followed by longlines, poles and lines, bottom and pelagic trawls, gillnets, purse seines, hand lines, and unspecified nets (SAU 2016). Most of the commercial harvest was caught by fishers from the U.S. (62%), Russian Federation (31%), and South Korea (6%); the remainder was taken by fishers from 37 other countries, including Japan and Canada (SAU 2016).

IV ENVIRONMENTAL CONSEQUENCES

4.1 Proposed Action

4.1.1 Direct Effects on Marine Mammals and Sea Turtles and Their Significance

The material in this section includes a summary of the expected potential effects (or lack thereof) of airgun sounds on marine mammals and sea turtles given in the PEIS, and reference to recent literature that has become available since the PEIS was released in 2011. A more comprehensive review of the relevant background information appears in § 3.4.4.3, § 3.6.4.3, § 3.7.4.3, § 3.8.4.3, and Appendix E of the PEIS. Relevant background information on the hearing abilities of marine mammals and sea turtles can also be found in the PEIS.

This section also includes estimates of the numbers of marine mammals that could be affected by the proposed seismic surveys. A description of the rationale for NSF's estimates of the numbers of individuals exposed to received sound levels ≥ 160 dB re 1 $\mu\text{Pa}_{\text{rms}}$ is also provided. Acoustic modeling for the Proposed Action was conducted by L-DEO, consistent with past EAs and determined to be acceptable by NMFS for use in the calculation of estimated Level A and B takes under the MMPA.

4.1.1.1 Summary of Potential Effects of Airgun Sounds

As noted in the PEIS (§ 3.4.4.3, § 3.6.4.3, § 3.7.4.3, § 3.8.4.3), the effects of sounds from airguns could include one or more of the following: tolerance, masking of natural sounds, behavioral disturbance, and at least in theory, temporary or permanent hearing impairment, or non-auditory physical or physiological effects (Richardson et al. 1995; Gordon et al. 2004; Nowacek et al. 2007; Southall et al. 2007; Erbe 2012; Peng et al. 2015; Erbe et al. 2016; Kunc et al. 2016; National Academies of Sciences, Engineering, and Medicine 2017; Weilgart 2017a). In some cases, a behavioral response to a sound can reduce the overall exposure to that sound (e.g., Finneran et al. 2015; Wensveen et al. 2015).

Permanent hearing impairment (PTS), in the unlikely event that it occurred, would constitute injury, but TTS is not considered an injury (Southall et al. 2007; Le Prell 2012). Rather, the onset of TTS has been considered an indicator that, if the animal is exposed to higher levels of that sound, physical damage is ultimately a possibility. Nonetheless, research has shown that sound exposure can cause cochlear neural degeneration, even when threshold shifts and hair cell damage are reversible (Kujawa and Liberman 2009; Liberman et al. 2016). These findings have raised some doubts as to whether TTS should continue to be considered a non-injurious effect (Weilgart 2014; Tougaard et al. 2015, 2016). Although the possibility cannot be entirely excluded, it is unlikely that the proposed surveys would result in any cases of temporary or permanent hearing impairment, or any significant non-auditory physical or physiological effects. If marine mammals encounter a survey while it is underway, some behavioral disturbance could result, but this would be localized and short-term.

Tolerance.—Numerous studies have shown that pulsed sounds from airguns are often readily detectable in the water at distances of many kilometers (e.g., Nieu Kirk et al. 2012). Several studies have shown that marine mammals at distances more than a few kilometers from operating seismic vessels often show no apparent response. 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 and toothed whales, and (less frequently) pinnipeds have been shown to react behaviorally to airgun pulses under some conditions, at other times mammals of all three types have shown no overt reactions. The relative responsiveness of baleen and toothed whales are quite variable.

Masking.—Masking effects of pulsed sounds (even from large arrays of airguns) on marine mammal calls and other natural sounds are expected to be limited, although there are few specific data on this. Because of the intermittent nature and low duty cycle of seismic pulses, animals can emit and receive sounds in the relatively quiet intervals between pulses. However, in exceptional situations, reverberation occurs for much or all of the interval between pulses (e.g., Simard et al. 2005; Clark and Gagnon 2006), which could mask calls. Situations with prolonged strong reverberation are infrequent. However, it is common for reverberation to cause some lesser degree of elevation of the background level between airgun pulses (e.g., Gedamke 2011; Guerra et al. 2011, 2016; Klinck et al. 2012; Guan et al. 2015), and this weaker reverberation presumably reduces the detection range of calls and other natural sounds to some degree. Guerra et al. (2016) reported that ambient noise levels between seismic pulses were elevated as a result of reverberation at ranges of 50 km from the seismic source. Based on measurements in deep water of the Southern Ocean, Gedamke (2011) estimated that the slight elevation of background levels during intervals between pulses reduced blue and fin whale communication space by as much as 36–51% when a seismic survey was operating 450–2800 km away. Based on preliminary modeling, Wittekind et al. (2016) reported that airgun sounds could reduce the communication range of blue and fin whales 2000 km from the seismic source. Nieu Kirk et al. (2012) and Blackwell et al. (2013) noted the potential for masking effects from seismic surveys on large whales.

Some baleen and toothed whales are known to continue calling in the presence of seismic pulses, and their calls usually can be heard between the pulses (e.g., Nieu Kirk et al. 2012; Thode et al. 2012; Bröker et al. 2013; Sciacca et al. 2016). Cerchio et al. (2014) suggested that the breeding display of humpback whales off Angola could be disrupted by seismic sounds, as singing activity declined with increasing received levels. In addition, some cetaceans are known to change their calling rates, shift their peak frequencies, or otherwise modify their vocal behavior in response to airgun sounds (e.g., Di Iorio and Clark 2010; Castellote et al. 2012; Blackwell et al. 2013, 2015). The hearing systems of baleen whales are undoubtedly more sensitive to low-frequency sounds than are the ears of the small odontocetes that have been studied directly (e.g., MacGillivray et al. 2014). The sounds important to small

odontocetes are predominantly at much higher frequencies than are the dominant components of airgun sounds, thus limiting the potential for masking. In general, masking effects of seismic pulses are expected to be minor, given the normally intermittent nature of seismic pulses. We are not aware of any information concerning masking of hearing in sea turtles.

Disturbance Reactions.—Disturbance includes a variety of effects, including subtle to conspicuous changes in behavior, movement, and displacement. Based on NMFS (2001, p. 9293), National Research Council (NRC 2005), and Southall et al. (2007), we believe that simple exposure to sound, or brief reactions that do not disrupt behavioral patterns in a potentially significant manner, do not constitute harassment or “taking”. By potentially significant, we mean, ‘in a manner that might have deleterious effects to the well-being of individual marine mammals or their populations’.

Reactions to sound, if any, depend on species, state of maturity, experience, current activity, reproductive state, time of day, and many other factors (Richardson et al. 1995; Wartzok et al. 2004; Southall et al. 2007; Weilgart 2007; Ellison et al. 2012). If a marine mammal does react briefly 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 (e.g., New et al. 2013a). 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 (Lusseau and Bejder 2007; Weilgart 2007; New et al. 2013b; Nowacek et al. 2015; Forney et al. 2017). Some studies have attempted modeling to assess consequences of effects from underwater noise at the population level (e.g., King et al. 2015; Costa et al. 2016a,b; Ellison et al. 2016; Harwood et al. 2016; Nowacek et al. 2016; Farmer et al. 2017).

Given the many uncertainties in predicting the quantity and types of impacts of noise on marine mammals, it is common practice to estimate how many marine mammals would be present within a particular distance of industrial activities and/or exposed to a particular level of industrial sound. In most cases, this approach likely overestimates the numbers of marine mammals that would be affected in some biologically important manner. The sound criteria used to estimate how many marine mammals could be disturbed to some biologically important degree by a seismic program are based primarily on behavioral observations of a few species. Detailed studies have been done on humpback, gray, bowhead, and sperm whales. 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.

Baleen Whales

Baleen whales generally tend to avoid operating airguns, but avoidance radii are quite variable. Whales are often reported to show no overt reactions to pulses from large arrays of airguns at distances beyond a few kilometers, even though the airgun pulses remain well above ambient noise levels out to much longer distances. However, baleen whales exposed to strong noise pulses from airguns often react by deviating from their normal migration route and/or interrupting their feeding and moving away. In the cases of migrating gray and bowhead whales, the observed changes in behavior appeared to be of little or no biological consequence to the animals. They simply avoided the sound source by displacing their migration route to varying degrees, but within the natural boundaries of the migration corridors (Malme et al. 1984; Malme and Miles 1985; Richardson et al. 1995).

Responses of *humpback whales* to seismic surveys have been studied during migration, on summer feeding grounds, and on Angolan winter breeding grounds; there has also been discussion of effects on the Brazilian wintering grounds. Off Western Australia, avoidance reactions began at 5–8 km from the array, and those reactions kept most pods ~3–4 km from the operating seismic boat; there was localized

displacement during migration of 4–5 km by traveling pods and 7–12 km by more sensitive resting pods of cow-calf pairs (McCauley et al. 1998, 2000). However, some individual humpback whales, especially males, approached within distances of 100–400 m.

Dunlop et al. (2015) reported that migrating humpback whales in Australia responded to a vessel operating a 20 in³ airgun by decreasing their dive time and speed of southward migration; however, the same responses were obtained during control trials without an active airgun, suggesting that humpbacks responded to the source vessel rather than the airgun. A ramp up was not superior to triggering humpbacks to move away from the vessel compared with a constant source at a higher level of 140 in³, although an increase in distance from the airgun(s) was noted for both sources (Dunlop et al. 2016a). Avoidance was also shown when no airguns were operational, indicating that the presence of the vessel itself had an effect on the response (Dunlop et al. 2016a,b). Overall, the results showed that humpbacks were more likely to avoid active small airgun sources (20 and 140 in³) within 3 km and received levels of at least 140 dB re 1 $\mu\text{Pa}^2 \cdot \text{s}$ (Dunlop et al. 2017a). Responses to ramp up and use of a large 3130 in³ array elicited greater behavioral changes in humpbacks when compared with small arrays (Dunlop et al. 2016c). Humpbacks reduced their southbound migration, or deviated from their path thereby avoiding the active array, when they were within 4 km of the active large airgun source, where received levels were >135 dB re 1 $\mu\text{Pa}^2 \cdot \text{s}$ (Dunlop et al. 2017b). These results are consistent with earlier studies (e.g., McCauley et al. 2000).

In the northwest Atlantic, sighting rates were significantly greater during non-seismic periods compared with periods when a full array was operating, and 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). In contrast, sightings of humpback whales from seismic vessels off the U.K. during 1994–2010 indicated that detection rates were similar during seismic and non-seismic periods, although sample sizes were small (Stone 2015). On their summer feeding grounds in southeast Alaska, there was no clear evidence of avoidance, despite the possibility of subtle effects, at received levels up to 172 re 1 μPa on an approximate rms basis (Malme et al. 1985). 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), but data from subsequent years indicated that there was no observable direct correlation between strandings and seismic surveys (IWC 2007).

There are no data on reactions of *right whales* to seismic surveys. However, Rolland et al. (2012) suggested that ship noise causes increased stress in right whales; they showed that baseline levels of stress-related faecal hormone metabolites decreased in North Atlantic right whales with a 6-dB decrease in underwater noise from vessels. Wright et al. (2011), Atkinson et al. (2015), Houser et al. (2016), and Lyamin et al. (2016) also reported that sound could be a potential source of stress for marine mammals.

Bowhead whales show that their responsiveness can be quite variable depending on their activity (migrating vs. feeding). Bowhead whales migrating west across the Alaskan Beaufort Sea in autumn, in particular, are unusually responsive, with substantial avoidance occurring out to distances of 20–30 km from a medium-sized airgun source (Miller et al. 1999; Richardson et al. 1999). Subtle but statistically significant changes in surfacing–respiration–dive cycles were shown by traveling and socializing bowheads exposed to airgun sounds in the Beaufort Sea, including shorter surfacings, shorter dives, and decreased number of blows per surfacing (Robertson et al. 2013). More recent research on bowhead whales corroborates earlier evidence that, during the summer feeding season, bowheads are less responsive to seismic sources (e.g., Miller et al. 2005; Robertson et al. 2013).

Bowhead whale calls detected in the presence and absence of airgun sounds have been studied extensively in the Beaufort Sea. Bowheads continue to produce calls of the usual types when exposed to airgun sounds on their summering grounds, although numbers of calls detected are significantly lower in the presence than in the absence of airgun pulses (Blackwell et al. 2013, 2015). Blackwell et al. (2013) reported that calling rates in 2007 declined significantly where received SPLs from airgun sounds were 116–129 dB re 1 μ Pa; at SPLs <108 dB re 1 μ Pa, calling rates were not affected. When data for 2007–2010 were analyzed, Blackwell et al. (2015) reported an initial increase in calling rates when airgun pulses became detectable; however, calling rates leveled off at a received CSEL_{10-min} (cumulative SEL over a 10-min period) of ~94 dB re 1 μ Pa²·s, decreased at CSEL_{10-min} >127 dB re 1 μ Pa²·s, and whales were nearly silent at CSEL_{10-min} >160 dB re 1 μ Pa²·s. Thus, bowhead whales in the Beaufort Sea apparently decreased their calling rates in response to seismic operations, although movement out of the area could also have contributed to the lower call detection rate (Blackwell et al. 2013, 2015).

A multivariate analysis of factors affecting the distribution of calling bowhead whales during their fall migration in 2009 noted that the southern edge of the distribution of calling whales was significantly closer to shore with increasing levels of airgun sound from a seismic survey a few hundred kilometers to the east of the study area (i.e., behind the westward-migrating whales; McDonald et al. 2010, 2011). It was not known whether this statistical effect represented a stronger tendency for quieting of the whales farther offshore in deeper water upon exposure to airgun sound, or an actual inshore displacement of whales.

There was no indication that *western gray whales* exposed to seismic sound 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) and 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). Similarly, no large changes in gray whale movement, respiration, or distribution patterns were observed during the seismic programs conducted in 2010 (Bröker et al. 2015; Gailey et al. 2016). Although sighting distances of gray whales from shore increased slightly during a 2-week seismic survey, this result was not significant (Muir et al. 2015). However, there may have been a possible localized avoidance response to high sound levels in the area (Muir et al. 2016). The lack of strong avoidance or other strong responses during the 2001 and 2010 programs was presumably in part a result of the comprehensive combination of real-time monitoring and mitigation measures designed to avoid exposing western gray whales to received SPLs above ~163 dB re 1 μ Pa_{rms} (Johnson et al. 2007; Nowacek et al. 2012, 2013b). In contrast, preliminary data collected during a seismic program in 2015 showed some displacement of animals from the feeding area and responses to lower sound levels than expected (Gailey et al. 2017; Sychenko et al. 2017).

Gray whales in BC, Canada, exposed to seismic survey sound levels up to ~170 dB re 1 μ Pa 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).

Various species of *Balaenoptera* (blue, sei, fin, and minke whales) have occasionally been seen in areas ensounded by airgun pulses. Sightings by observers on seismic vessels using large arrays off the U.K. from 1994–2010 showed that the detection rate for minke whales was significantly higher when airguns were not operating; however, during surveys with small arrays, the detection rates for minke whales were similar during seismic and non-seismic periods (Stone 2015). Sighting rates for fin and sei whales were similar when large arrays of airguns were operating vs. silent (Stone 2015). All baleen whales combined tended to exhibit localized avoidance, remaining significantly farther (on average) from large arrays (median closest point of approach or CPA of ~1.5 km) during seismic operations compared with non-seismic periods (median CPA ~1.0 km; Stone 2015). In addition, fin and minke whales were more often oriented away from the vessel while a large airgun array was active compared with periods of inactivity (Stone 2015). Singing fin whales in the Mediterranean moved away from an operating airgun array, and their song notes had lower bandwidths during periods with vs. without airgun sounds (Castellote et al. 2012).

During seismic surveys in the northwest Atlantic, baleen whales as a group showed localized avoidance of the operating array (Moulton and Holst 2010). Sighting rates were significantly lower during seismic operations compared with non-seismic periods. Baleen whales were seen on average 200 m farther from the vessel during airgun activities vs. non-seismic periods, and these whales more often swam away from the vessel when seismic operations were underway compared with periods when no airguns were operating (Moulton and Holst 2010). Blue whales were seen significantly farther from the vessel during single airgun operations, ramp up, and all other airgun operations compared with non-seismic periods (Moulton and Holst 2010). Similarly, fin whales were seen at significantly farther distances during ramp up than during periods without airgun operations; there was also a trend for fin whales to be sighted farther from the vessel during other airgun operations, but the difference was not significant (Moulton and Holst 2010). Minke whales were seen significantly farther from the vessel during periods with than without seismic operations (Moulton and Holst 2010). Minke whales were also more likely to swim away and less likely to approach during seismic operations compared to periods when airguns were not operating (Moulton and Holst 2010). However, Matos (2015) reported no change in sighting rates of minke whales in Vestfjorden, Norway, during ongoing seismic surveys outside of the fjord. Vilela et al. (2016) cautioned that environmental conditions should be taken into account when comparing sighting rates during seismic surveys, as spatial modeling showed that differences in sighting rates of rorquals (fin and minke whales) during seismic periods and non-seismic periods during a survey in the Gulf of Cadiz could be explained by environmental variables.

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 with substantial increases in the population over recent years, despite intermittent seismic exploration (and much ship traffic) in that area for decades. The western Pacific gray whale population continued to feed off Sakhalin Island every summer, despite seismic surveys in the region. In addition, bowhead whales have continued to travel to the eastern Beaufort Sea each summer, and their numbers have increased notably, despite seismic exploration in their summer and autumn range for many years. Pirotta et al. (2018) used a dynamic state model of behavior and physiology to assess the consequences of disturbance (e.g., seismic surveys) on whales (in this case, blue whales). They found that the impact of localized, acute disturbance (e.g., seismic surveys) depended on the whale's behavioral response, with whales that remained in the affected area

having a greater risk of reduced reproductive success than whales that avoided the disturbance. Chronic, but weaker disturbance (e.g., vessel traffic) appeared to have less effect on reproductive success.

Toothed Whales

Little systematic information is available about reactions of toothed whales to sound pulses. However, there are recent systematic studies on sperm whales, and there is an increasing amount of information about responses of various odontocetes to seismic surveys based on monitoring studies. 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., Stone and Tasker 2006; Moulton and Holst 2010; Barry et al. 2012; Wole and Myade 2014; Stone 2015; Monaco et al. 2016). 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.

Observations from seismic vessels using large arrays off the U.K. from 1994–2010 indicated that detection rates were significantly higher for killer whales, white-beaked dolphins, and Atlantic white-sided dolphins when airguns were not operating; detection rates during seismic vs. non-seismic periods were similar during seismic surveys using small arrays (Stone 2015). Detection rates for long-finned pilot whales, Risso’s dolphins, bottlenose dolphins, and short-beaked common dolphins were similar during seismic (small or large array) vs. non-seismic operations (Stone 2015). CPA distances for killer whales, white-beaked dolphins, and Atlantic white-sided dolphins were significantly farther (>0.5 km) from large airgun arrays during periods of airgun activity compared with periods of inactivity, with significantly more animals traveling away from the vessel during airgun operation (Stone 2015). Observers’ records suggested that fewer cetaceans were feeding and fewer delphinids were interacting with the survey vessel (e.g., bow-riding) during periods with airguns operating (Stone 2015).

During seismic surveys in the northwest Atlantic, delphinids as a group showed some localized avoidance of the operating array (Moulton and Holst 2010). The mean initial detection distance was significantly farther (by ~200 m) during seismic operations compared with periods when the seismic source was not active; however, there was no significant difference between sighting rates (Moulton and Holst 2010). The same results were evident when only long-finned pilot whales were considered.

Preliminary findings of a monitoring study of *narwhals* in Melville Bay, Greenland, (summer and fall 2012) showed no short-term effects of seismic survey activity on narwhal distribution, abundance, migration timing, and feeding habits (Heide-Jørgensen et al. 2013a). In addition, there were no reported effects on narwhal hunting. These findings do not seemingly support a suggestion by Heide-Jørgensen et al. (2013b) that seismic surveys in Baffin Bay may have delayed the migration timing of narwhals, thereby increasing the risk of narwhals to ice entrapment.

The beluga, however, is a species that (at least at times) shows long-distance (10s of km) avoidance of seismic vessels (e.g., Miller et al. 2005). 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, but the animals tolerated high received levels of sound before exhibiting aversive behaviors (e.g., Finneran et al. 2000, 2002, 2005). Schlundt et al. (2016) also reported that bottlenose dolphins exposed to multiple airgun pulses exhibited some anticipatory behavior.

Most studies of *sperm whales* exposed to airgun sounds indicate that the sperm whale shows considerable tolerance of airgun pulses; in most cases the whales do not show strong avoidance (e.g., Stone and Tasker 2006; Moulton and Holst 2010). Winsor et al. (2017) outfitted sperm whales in

the Gulf of Mexico with satellite tags to examine their spatial distribution in relation to seismic surveys. They found no evidence of avoidance or changes in orientation by sperm whales to active seismic vessels. Based on data collected by observers on seismic vessels off the U.K. from 1994–2010, detection rates for sperm whales were similar when large arrays of airguns were operating vs. silent; however, during surveys with small arrays, the detection rate was significantly higher when the airguns were not in operation (Stone 2015). Foraging behavior can also be altered upon exposure to airgun sound (e.g., Miller et al. 2009), which according to Farmer et al. (2017), could have significant consequences on individual fitness. Preliminary data from the Gulf of Mexico show a correlation between reduced sperm whale acoustic activity and periods with airgun operations (Sidorovskaia et al. 2014).

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) and/or change their behavior in response to sounds from vessels (e.g., Pirotta et al. 2012). Thus, it is likely that most beaked whales would also show strong avoidance of an approaching seismic vessel. Observations from seismic vessels off the U.K. from 1994–2010 indicated that detection rates of beaked whales were significantly higher ($p < 0.05$) when airguns were not operating vs. when a large array was in operation, although sample sizes were small (Stone 2015). 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 (e.g., Simard et al. 2005).

The limited available data suggest that *harbor porpoises* show stronger avoidance of seismic operations than do Dall's porpoises. The apparent tendency for greater responsiveness in the harbor porpoise is consistent with its relative responsiveness to boat traffic and some other acoustic sources (Richardson et al. 1995; Southall et al. 2007). Based on data collected by observers on seismic vessels off the U.K. from 1994–2010, detection rates of harbor porpoises were significantly higher when airguns were silent vs. when large or small arrays were operating (Stone 2015). In addition, harbor porpoises were seen farther away from the array when it was operating vs. silent, and were most often seen traveling away from the airgun array when it was in operation (Stone 2015). Thompson et al. (2013) reported decreased densities and reduced acoustic detections of harbor porpoise in response to a seismic survey in Moray Firth, Scotland, at ranges of 5–10 km (SPLs of 165–172 dB re 1 μPa , SELs of 145–151 dB $\mu\text{Pa}^2 \cdot \text{s}$). For the same survey, Pirotta et al. (2014) reported that the probability of recording a porpoise buzz decreased by 15% in the ensonified area, and that the probability was positively related to the distance from the seismic ship; the decreased buzzing occurrence may indicate reduced foraging efficiency. Nonetheless, animals returned to the area within a few hours (Thompson et al. 2013). In a captive facility, harbor porpoise showed avoidance of a pool with elevated sound levels, but search time for prey within that pool was no different than in a quieter pool (Kok et al. 2017).

Kastelein et al. (2013a) reported that a harbor porpoise showed no response to an impulse sound with an SEL below 65 dB, but a 50% brief response rate was noted at an SEL of 92 dB and an SPL of 122 dB re 1 $\mu\text{Pa}_{0\text{-peak}}$. However, Kastelein et al. (2012c) reported a 50% detection threshold at a SEL of 60 dB to a similar impulse sound; this difference is likely attributable to the different transducers used during the two studies (Kastelein et al. 2013c). Van Beest et al. (2018) exposed five harbor porpoise to a single 10 in³ airgun for 1 min at 2–3 s intervals at ranges of 420–690 m and levels of 135–147 dB $\mu\text{Pa}^2 \cdot \text{s}$. One porpoise moved away from the sound source but returned to natural movement patterns within 8 h, and two porpoises had shorter and shallower dives but returned to natural behaviors within 24 h.

Odontocete reactions to large arrays of airguns are variable and, at least for delphinids, seem to be confined to a smaller radius than has been observed for the more responsive of the mysticetes and some

other odontocetes. A ≥ 170 dB disturbance criterion (rather than ≥ 160 dB) is considered appropriate for delphinids, which tend to be less responsive than the more responsive cetaceans. NMFS is currently developing new guidance for predicting behavioral effects (Scholik-Schlomer 2015). As behavioral responses are not consistently associated with received levels, some authors have made recommendations on different approaches to assess behavioral reactions (e.g., Gomez et al. 2016; Harris et al. 2017).

Pinnipeds

Pinnipeds are not likely to show a strong avoidance reaction to an airgun array. Visual monitoring from seismic vessels has shown only slight (if any) avoidance of airguns by pinnipeds and only slight (if any) changes in behavior. However, telemetry work has suggested that avoidance and other behavioral reactions may be stronger than evident to date from visual studies (Thompson et al. 1998). Observations from seismic vessels operating large arrays off the U.K. from 1994–2010 showed that the detection rate for gray seals was significantly higher when airguns were not operating; for surveys using small arrays, the detection rates were similar during seismic vs. non-seismic operations (Stone 2015). No significant differences in detection rates were apparent for harbor seals during seismic and non-seismic periods (Stone 2015). There were no significant differences in CPA distances of grey or harbor seals during seismic vs. non-seismic periods (Stone 2015). L alas and McConnell (2015) made observations of New Zealand fur seals from a seismic vessel operating a 3090 in³ airgun array in New Zealand during 2009. However, the results from the study were inconclusive in showing whether New Zealand fur seals respond to seismic sounds. Reichmuth et al. (2016) exposed captive spotted and ringed seals to single airgun pulses; only mild behavioral responses were observed.

Sea Turtles

Several recent papers discuss the morphology of the turtle ear (e.g., Christensen-Dalsgaard et al. 2012; Willis et al. 2013) and the hearing ability of sea turtles (e.g., Martin et al. 2012; Piniak et al. 2012a,b; Lavender et al. 2014). The limited available data indicate that sea turtles will hear airgun sounds and sometimes exhibit localized avoidance (see PEIS, § 3.4.4.3). In additional, Nelms et al. (2016) suggest that sea turtles could be excluded from critical habitats during seismic surveys.

DeRuiter and Doukara (2012) observed that immediately following an airgun pulse, small numbers of basking loggerhead turtles (6 of 86 turtles observed) exhibited an apparent startle response (sudden raising of the head and splashing of flippers, occasionally accompanied by blowing bubbles from the beak and nostrils, followed by a short dive). Diving turtles (49 of 86 individuals) were observed at distances from the center of the airgun array ranging from 50–839 m. The estimated sound level at the median distance of 130 m was 191 dB re 1 $\mu\text{Pa}_{\text{peak}}$. These observations were made during ~150 h of vessel-based monitoring from a seismic vessel operating an airgun array (13 airguns, 2440 in³) off Algeria; there was no corresponding observation effort during periods when the airgun array was inactive (DeRuiter and Doukara 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. To the extent that there are any impacts on sea turtles, seismic operations in or near areas where turtles concentrate would likely have the greatest impact. There are no specific data that demonstrate the consequences to sea turtles if seismic operations with large or small arrays of airguns occur in important areas at biologically important times of the 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; van der Wal et al. 2016).

Hearing Impairment and Other Physical Effects.—Temporary or permanent hearing impairment is a possibility when marine mammals are exposed to very strong sounds. TTS has been demonstrated and studied in certain captive odontocetes and pinnipeds exposed to strong sounds (reviewed by Southall et al. 2007; Finneran 2015). However, there has been no specific documentation of TTS let alone permanent hearing damage, i.e., PTS, in free-ranging marine mammals exposed to sequences of airgun pulses during realistic field conditions.

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, one would (as a minimum) need to allow for the sequence of distances at which airgun pulses would occur, and for the dependence of received SEL on distance in the region of the seismic operation (e.g., Breitzke and Bohlen 2010; Laws 2012). At the present state of knowledge, it is also necessary to assume that the effect is directly related to total received energy (SEL); however, this assumption is likely an over-simplification (Finneran 2012). There is recent evidence that auditory effects in a given animal are not a simple function of received acoustic energy (Finneran 2015). Frequency, duration of the exposure, and occurrence of gaps within the exposure can also influence the auditory effect (Finneran and Schlundt 2010, 2011, 2013; Finneran et al. 2010a,b; Popov et al. 2011, 2013; Ketten 2012; Finneran 2012, 2015; Kastelein et al. 2012a,b; 2013b,c, 2014, 2015a, 2016a,b, 2017; Supin et al. 2016).

Studies have shown that the SEL required for TTS onset to occur increases with intermittent exposures, with some auditory recovery during silent periods between signals (Finneran et al. 2010b; Finneran and Schlundt 2011). Studies on bottlenose dolphins by Finneran et al. (2015) indicate that the potential for seismic surveys using airguns to cause auditory effects on dolphins could be lower than previously thought. Based on behavioral tests, no measurable TTS was detected in three bottlenose dolphins after exposure to 10 impulses from a seismic airgun with a cumulative SEL of up to ~ 195 dB re $1 \mu\text{Pa}^2 \cdot \text{s}$ (Finneran et al. 2015; Schlundt et al. 2016). However, auditory evoked potential measurements were more variable; one dolphin showed a small (9 dB) threshold shift at 8 kHz (Finneran et al. 2015; Schlundt et al. 2016).

Studies have also shown that the SEL necessary to elicit TTS can depend substantially on frequency, with susceptibility to TTS increasing with increasing frequency above 3 kHz (Finneran and Schlundt 2010, 2011; Finneran 2012). When beluga whales were exposed to fatiguing noise with sound levels of 165 dB re $1 \mu\text{Pa}$ for durations of 1–30 min at frequencies of 11.2–90 kHz, the highest TTS with the longest recovery time was produced by the lower frequencies (11.2 and 22.5 kHz); TTS effects also gradually increased with prolonged exposure time (Popov et al. 2013). Additionally, Popov et al. (2015) demonstrated that the impacts of TTS include deterioration of signal discrimination. Kastelein et al. (2015b, 2017) reported that exposure to multiple pulses with most energy at low frequencies can lead to TTS at higher frequencies in some cetaceans, such as the harbor porpoise. When a porpoise was exposed to 10 and 20 consecutive shots (mean shot interval ~ 17 s) from two airguns with a SEL_{cum} of 188 and 191 $\mu\text{Pa}^2 \cdot \text{s}$, respectively, significant TTS occurred at a hearing frequency of 4 kHz and not at lower hearing frequencies that were tested, despite the fact that most of the airgun energy was < 1 kHz; recovery occurred within 12 min post exposure (Kastelein et al. 2017).

Popov et al. (2016) reported that TTS produced by exposure to a fatiguing noise was larger during the first session (or naïve subject state) with a beluga whale than TTS that resulted from the same sound in subsequent sessions (experienced subject state). Similarly, several other studies have shown that some marine mammals (e.g., bottlenose dolphins, false killer whales) can decrease their hearing sensitivity in

order to mitigate the impacts of exposure to loud sounds (e.g., Nachtigall and Supin 2013, 2014, 2015, 2016; Nachtigall et al. 2017).

Previous information on TTS for odontocetes was primarily derived from studies on the bottlenose dolphin and beluga, and that for pinnipeds has mostly been obtained from California sea lions and elephant seals (see § 3.6.4.3, § 3.7.4.3, § 3.8.4.3 and Appendix E of the PEIS). Thus, it is inappropriate to assume that onset of TTS occurs at similar received levels in all cetaceans or pinnipeds (*cf.* Southall et al. 2007). Some cetaceans or pinnipeds could incur TTS at lower sound exposures than are necessary to elicit TTS in the beluga and bottlenose dolphin or California sea lion and elephant seal, respectively.

Several studies on TTS in porpoises (e.g., Lucke et al. 2009; Popov et al. 2011; Kastelein et al. 2012a, 2013a,b, 2014, 2015a) indicate that received levels that elicit onset of TTS are lower in porpoises than in other odontocetes. Kastelein et al. (2012a) exposed a harbor porpoise to octave band noise centered at 4 kHz for extended periods. A 6-dB TTS occurred with SELs of 163 dB and 172 dB for low-intensity sound and medium-intensity sound, respectively; high-intensity sound caused a 9-dB TTS at a SEL of 175 dB (Kastelein et al. 2012a). Kastelein et al. (2013b) exposed a harbor porpoise to a long, continuous 1.5-kHz tone, which induced a 14-dB TTS with a total SEL of 190 dB. Popov et al. (2011) examined the effects of fatiguing noise on the hearing threshold of Yangtze finless porpoises when exposed to frequencies of 32–128 kHz at 140–160 dB re 1 μ Pa for 1–30 min. They found that an exposure of higher level and shorter duration produced a higher TTS than an exposure of equal SEL but of lower level and longer duration. Popov et al. (2011) reported a TTS of 25 dB for a Yangtze finless porpoise that was exposed to high levels of 3-min pulses of half-octave band noise centered at 45 kHz with an SEL of 163 dB.

For the harbor porpoise, Tougaard et al. (2015) have suggested an exposure limit for TTS as an SEL of 100–110 dB above the pure tone hearing threshold at a specific frequency; they also suggested an exposure limit of $L_{eq-fast}$ (rms average over the duration of the pulse) of 45 dB above the hearing threshold for behavioral responses (i.e., negative phonotaxis). In addition, according to Wensveen et al. (2014) and Tougaard et al. (2015), M-weighting, as used by Southall et al. (2007), might not be appropriate for the harbor porpoise. Thus, Wensveen et al. (2014) developed six auditory weighting functions for the harbor porpoise that could be useful in predicting TTS onset. Mulsow et al. (2015) suggested that basing weighting functions on equal latency/loudness contours may be more appropriate than M-weighting for marine mammals. Simulation modeling to assess the risk of sound exposure to marine mammals (gray seal and harbor porpoise) showed that SEL is most strongly influenced by the weighting function (Donovan et al. 2017). Houser et al. (2017) provide a review of the development and application of auditory weighting functions, as well as recommendations for future work.

Initial evidence from exposures to non-pulses has also suggested that some pinnipeds (harbor seals in particular) incur TTS at somewhat lower received levels than do most small odontocetes exposed for similar durations (Kastak et al. 1999, 2005, 2008; Ketten et al. 2001). Kastelein et al. (2012b) exposed two harbor seals to octave-band white noise centered at 4 kHz at three mean received SPLs of 124, 136, and 148 dB re 1 μ Pa; TTS >2.5 dB was induced at an SEL of 170 dB (136 dB SPL for 60 min), and the maximum TTS of 10 dB occurred after a 120-min exposure to 148 dB re 1 μ Pa or an SEL of 187 dB. Kastelein et al. (2013c) reported that a harbor seal unintentionally exposed to the same sound source with a mean received SPL of 163 dB re 1 μ Pa for 1 h induced a 44 dB TTS. For a harbor seal exposed to octave-band white noise centered at 4 kHz for 60 min with mean SPLs of 124–148 re 1 μ Pa, the onset of PTS would require a level of at least 22 dB above the TTS onset (Kastelein et al. 2013c). Reichmuth et al. (2016) exposed captive spotted and ringed seals to single airgun pulses with SELs of 165–181 dB and

SPLs (peak to peak) of 190–207 re 1 μ Pa; no low-frequency TTS was observed.

Hermannsen et al. (2015) reported that there is little risk of hearing damage to harbor seals or harbor porpoises when using single airguns in shallow water. Similarly, it is unlikely that a marine mammal would remain close enough to a large airgun array for sufficiently long to incur TTS, let alone PTS. However, Gedamke et al. (2011), based on preliminary simulation modeling that attempted to allow for various uncertainties in assumptions and variability around population means, suggested that some baleen whales whose CPA to a seismic vessel is 1 km or more could experience TTS.

There is no specific evidence that exposure to pulses of airgun sound can cause PTS in any marine mammal, even with large arrays of airguns. However, given the possibility that some mammals close to an airgun array might incur at least mild TTS, 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. 372ff; Gedamke et al. 2011). In terrestrial animals, exposure to sounds sufficiently strong to elicit a large TTS induces physiological and structural changes in the inner ear, and at some high level of sound exposure, these phenomena become non-recoverable (Le Prell 2012). At this level of sound exposure, TTS grades into PTS. 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 (e.g., Kastak and Reichmuth 2007; Kastak et al. 2008).

The new noise exposure criteria for marine mammals that were released by NMFS (2016a, 2018a) account for the newly-available scientific data on TTS, the expected offset between TTS and PTS thresholds, differences in the acoustic frequencies to which different marine mammal groups are sensitive, and other relevant factors. For impulsive sounds, such as airgun pulses, the thresholds use dual metrics of cumulative SEL (SEL_{cum} over 24 hours) and Peak SPL_{flat}. Onset of PTS is assumed to be 15 dB higher when considering SEL_{cum} and 6 dB higher when considering SPL_{flat}. Different thresholds are provided for the various hearing groups, including LF cetaceans (e.g., baleen whales), MF cetaceans (e.g., most delphinids), HF cetaceans (e.g., porpoise and *Kogia* spp.), phocids underwater (PW), and otariids underwater (OW).

Nowacek et al. (2013a) concluded that current scientific data indicate that seismic airguns have a low probability of directly harming marine life, except at close range. Several aspects of the planned monitoring and mitigation measures for this project 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. Also, many marine mammals and (to a limited degree) sea turtles 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 would reduce or (most likely) avoid any possibility of hearing impairment. Aarts et al. (2016) noted that an understanding of animal movement is necessary in order to estimate the impact of anthropogenic sound on cetaceans.

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. Gray and Van Waerebeek (2011) have suggested a cause-effect relationship between a seismic survey off Liberia in 2009 and the erratic movement, postural instability, and akinesia in a pantropical spotted dolphin based on spatially and temporally close association with the airgun array. It is possible that some marine mammal species (i.e., beaked whales) are especially susceptible to injury and/or stranding when exposed to strong transient sounds (e.g., Southall et al. 2007).

Ten cases of cetacean strandings in the general area where a seismic survey was ongoing have led to speculation concerning a possible link between seismic surveys and strandings (Castellote and Llorens 2016). An analysis of stranding data found that the number of long-finned pilot whale strandings along Ireland's coast increased with seismic surveys operating offshore (McGeady et al. 2016). However, there is no definitive evidence that any of these effects occur even for marine mammals in close proximity to large arrays of airguns. Morell et al. (2017) examined the inner ears of long-finned pilot whales after a mass stranding in Scotland and reported damage to the cochlea compatible with over-exposure from underwater noise; however, no seismic surveys were occurring in the vicinity in the days leading up to the stranding.

Since 1991, there have been 67 Marine Mammal Unusual Mortality Events (UME) in the U.S. (NMFS 2018c). In a hearing to examine the Bureau of Ocean Energy Management's 2017–2022 OCS Oil and Gas Leasing Program (<http://www.energy.senate.gov/public/index.cfm/hearings-and-business-meetings?ID=110E5E8F-3A65-4BEC-9D25-5D843A0284D3>), it was Dr. Knapp's (a geologist from the University of South Carolina) interpretation that there was no evidence to suggest a correlation between UMEs and seismic surveys given the similar percentages of UMEs in the Pacific, Atlantic, and Gulf of Mexico, and the greater activity of oil and gas exploration in the Gulf of Mexico.

Non-auditory effects, if they occur at all, would presumably be limited to short distances and to activities that extend over a prolonged period. 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. The brief duration of exposure of any given mammal, the deep water in the survey area, and the planned monitoring and mitigation measures would further reduce the probability of exposure of marine mammals to sounds strong enough to induce non-auditory physical effects.

Sea Turtles

There is substantial overlap in the frequencies that sea turtles detect versus 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 (see § 3.4.4 of the PEIS). This suggests that sounds from an airgun array might cause temporary hearing impairment in sea turtles if they do not avoid the (unknown) radius where TTS occurs (see Nelms et al. 2016). However, exposure duration during the proposed surveys would be much less than during the aforementioned studies. Also, recent monitoring studies show that some sea turtles do show localized movement away from approaching airguns. 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.

The U.S. Navy has proposed the following criteria for the onset of hearing impairment for sea turtles: 232 dB re 1 μ Pa SPL (peak) and 204 dB re 1 μ Pa²·s SEL_{cum} (weighted) for PTS; and 226 dB peak and 189 dB weighted SEL for TTS (USN 2017). Although it is possible that exposure to airgun sounds could cause mortality or mortal injuries in sea turtles close to the source, this has not been demonstrated and seems highly unlikely (Popper et al. 2014), especially because sea turtles appear to be resistant to explosives (Ketten et al. 2005 *in* Popper et al. 2014). Nonetheless, Popper et al. (2014) proposed sea turtle mortality/mortal injury criteria of 210 dB SEL or >207 dB_{peak} for sounds from seismic airguns; however, these criteria were largely based on impacts of pile-driving sound on fish.

The PSOs stationed on R/V *Langseth* would watch for sea turtles, and airgun operations would be shut down if a turtle enters the designated EZ.

4.1.1.2 Possible Effects of Other Acoustic Sources

The Kongsberg EM 122 MBES and Knudsen Chirp 3260 SBP would be operated from the source vessel during the proposed surveys. Information about this equipment was provided in § 2.2.3.1 of the PEIS. A review of the expected potential effects (or lack thereof) of MBESs, SBPs, and pingers on marine mammals and sea turtles appears in § 3.4.4.3, § 3.6.4.3, § 3.7.4.3, § 3.8.4.3, and Appendix E of the PEIS.

There has been some recent attention given to the effects of MBES on marine mammals, as a result of a report issued in September 2013 by an IWC independent scientific review panel linking the operation of an MBES to a mass stranding of melon-headed whales off Madagascar (Southall et al. 2013). During May–June 2008, ~100 melon-headed whales entered and stranded in the Loza Lagoon system in northwest Madagascar at the same time that a 12-kHz MBES survey was being conducted ~65 km away off the coast. In conducting a retrospective review of available information on the event, an independent scientific review panel concluded that the Kongsberg EM 120 MBES was the most plausible behavioral trigger for the animals initially entering the lagoon system and eventually stranding. The independent scientific review panel, however, identified that an unequivocal conclusion on causality of the event was not possible because of the lack of information about the event and a number of potentially contributing factors. Additionally, the independent review panel report indicated that this incident was likely the result of a complicated confluence of environmental, social, and other factors that have a very low probability of occurring again in the future, but recommended that the potential be considered in environmental planning. It should be noted that this event is the first known marine mammal mass stranding closely associated with the operation of an MBES. Leading scientific experts knowledgeable about MBES expressed concerns about the independent scientific review panel analyses and findings (Bernstein 2013).

Reference has also been made that two beaked whales stranded in the Gulf of California in 2002 were observed during a seismic survey in the region by the R/V *Ewing* (Malakoff 2002, Cox et al. 2006 *in* PEIS:3-136), which used a similar MBES system. As noted in the PEIS, however, “The link between the stranding and the seismic surveys was inconclusive and not based on any physical evidence” (Hogarth 2002, Yoder 2002 *in* PEIS:3-190).

Lurton (2016) modeled MBES radiation characteristics (pulse design, source level, and radiation directivity pattern) applied to a low-frequency (12-kHz), 240-dB source-level system like that used on R/V *Langseth*. Using Southall et al. (2007) thresholds, he found that injury impacts were possible only at very short distances, e.g., at 5 m for maximum SPL and 12 m for cumulative SEL for cetaceans; corresponding distances for behavioral response were 9 m and 70 m. For pinnipeds, “all ranges are multiplied by a factor of 4” (Lurton 2016:209).

There is no available information on marine mammal behavioral response to MBES sounds (Southall et al. 2013) or sea turtle responses to MBES systems. Much of the literature on marine mammal response to sonars relates to the types of sonars used in naval operations, including low-frequency, mid-frequency, and high-frequency active sonars (see review by Southall et al. 2016). However, the MBES sounds are quite different from naval sonars. Ping duration of the MBES is very short relative to 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 beamwidth; naval sonars often use near-horizontally-directed sound. In addition, naval sonars have higher duty cycles. These factors would all reduce the sound energy received from the MBES relative to

that from naval sonars.

In the fall of 2006, an Ocean Acoustic Waveguide Remote Sensing (OAWRS) experiment was carried out in the Gulf of Maine (Gong et al. 2014); the OAWRS emitted three frequency-modulated (FM) pulses centered at frequencies of 415, 734, and 949 Hz (Risch et al. 2012). Risch et al. (2012) found a reduction in humpback whale song in the Stellwagen Bank National Marine Sanctuary during OAWRS activities that were carried out ~200 km away; received levels in the sanctuary were 88–110 dB re 1 μ Pa. In contrast, Gong et al. (2014) reported no effect of the OAWRS signals on humpback whale vocalizations in the Gulf of Maine. Range to the source, ambient noise, and/or behavioral state may have differentially influenced the behavioral responses of humpbacks in the two areas (Risch et al. 2014).

Deng et al. (2014) measured the spectral properties of pulses transmitted by three 200-kHz echosounders and found that they generated weaker sounds at frequencies below the center frequency (90–130 kHz). These sounds are within the hearing range of some marine mammals, and the authors suggested that they could be strong enough to elicit behavioral responses within close proximity to the sources, although they would be well below potentially harmful levels. Hastie et al. (2014) reported behavioral responses by gray seals to echosounders with frequencies of 200 and 375 kHz. Short-finned pilot whales increased their heading variance in response to an EK60 echosounder with a resonant frequency of 38 kHz (Quick et al. 2017), and significantly fewer beaked whale vocalizations were detected while an EK60 echosounder was active vs. passive (Cholewiak et al. 2017).

Despite the aforementioned information that has recently become available, this Final EA remains in agreement with the assessment presented in § 3.4.7, 3.6.7, 3.7.7, and 3.8.7 of the PEIS that operation of MBESs, SBPs, and pingers is not likely to impact marine mammals and is not expected to affect sea turtles, (1) given the lower acoustic exposures relative to airguns and (2) because the intermittent and/or narrow downward-directed nature of these sounds would result in no more than one or two brief ping exposures of any individual marine mammal or sea turtle given the movement and speed of the vessel. Also, for sea turtles, the associated frequency ranges are above their known hearing range.

4.1.1.3 Other Possible Effects of Seismic Surveys

Other possible effects of seismic surveys on marine mammals and/or sea turtles include masking by vessel noise, disturbance by vessel presence or noise, and injury or mortality from collisions with vessels or entanglement in seismic gear.

Vessel noise from R/V *Langseth* could affect marine animals in the proposed survey area. Houghton et al. (2015) proposed that vessel speed is the most important predictor of received noise levels, and Putland et al. (2017) also reported reduced sound levels with decreased vessel speed. Sounds produced by large vessels generally dominate ambient noise at frequencies from 20–300 Hz (Richardson et al. 1995). However, some energy is also produced at higher frequencies (Hermannsen et al. 2014); low levels of high-frequency sound from vessels have been shown to elicit responses in harbor porpoise (Dyndo et al. 2015). Increased levels of ship noise also affect foraging by porpoise (Teilmann et al. 2015; Wisniewska et al. 2018). Wisniewska et al. (2018) suggest that a decrease in foraging success could have long-term fitness consequences.

Ship noise, through masking, can reduce the effective communication distance of a marine mammal if the frequency of the sound source is close to that used by the animal, and if the sound is present for a significant fraction of time (e.g., Richardson et al. 1995; Clark et al. 2009; Jensen et al. 2009; Gervaise et al. 2012; Hatch et al. 2012; Rice et al. 2014; Dunlop 2015; Erbe et al. 2016; Jones et al. 2017; Putland et al. 2017; Cholewiak et al. 2018). In addition to the frequency and duration of the

masking sound, the strength, temporal pattern, and location of the introduced sound also play a role in the extent of the masking (Branstetter et al. 2013, 2016; Finneran and Branstetter 2013; Sills et al. 2017). Branstetter et al. (2013) reported that time-domain metrics are also important in describing and predicting masking. In order to compensate for increased ambient noise, some cetaceans are known to increase the source levels of their calls in the presence of elevated noise levels from shipping, shift their peak frequencies, or otherwise change their vocal behavior (e.g., Parks et al. 2011, 2012, 2016a,b; Castellote et al. 2012; Melcón et al. 2012; Azzara et al. 2013; Tyack and Janik 2013; Luís et al. 2014; Sairanen 2014; Papale et al. 2015; Bittencourt et al. 2016; Dahlheim and Castellote 2016; Gospić and Picciulin 2016; Gridley et al. 2016; Heiler et al. 2016; Martins et al. 2016; O'Brien et al. 2016; Tenessen and Parks 2016). Similarly, harbor seals increased the minimum frequency and amplitude of their calls in response to vessel noise (Matthews 2017); however, harp seals did not increase their call frequencies in environments with increased low-frequency sounds (Terhune and Bosker 2016).

Holt et al. (2015) reported that changes in vocal modifications can have increased energetic costs for individual marine mammals. A negative correlation between the presence of some cetacean species and the number of vessels in an area has been demonstrated by several studies (e.g., Campana et al. 2015; Culloch et al. 2016; Oakley et al. 2017). Based on modeling, Halliday et al. (2017) suggested that shipping noise can be audible more than 100 km away and could affect the behavior of a marine mammal at a distance of 52 km in the case of tankers.

Baleen whales are thought to be more sensitive to sound at these low frequencies than are toothed whales (e.g., MacGillivray et al. 2014), possibly causing localized avoidance of the proposed survey areas during seismic operations. Reactions of gray and humpback whales to vessels have been studied, and there is limited information available about the reactions of right whales and narwhals (fin, blue, and minke whales). Reactions of humpback whales to boats are variable, ranging from approach to avoidance (Payne 1978; Salden 1993). Baker et al. (1982, 1983) and Baker and Herman (1989) found humpbacks often move away when vessels are within several kilometers. Humpbacks seem less likely to react overtly when actively feeding than when resting or engaged in other activities (Krieger and Wing 1984, 1986). Increased levels of ship noise have been shown to affect foraging by humpback whales (Blair et al. 2016). Fin whale sightings in the western Mediterranean were negatively correlated with the number of vessels in the area (Campana et al. 2015). Minke whales and gray seals have shown slight displacement in response to construction-related vessel traffic (Anderwald et al. 2013).

Many odontocetes show considerable tolerance of vessel traffic, although they sometimes react at long distances if confined by ice or shallow water, if previously harassed by vessels, or have had little or no recent exposure to ships (Richardson et al. 1995). Dolphins of many species tolerate and sometimes approach vessels (e.g., Anderwald et al. 2013). Some dolphin species approach moving vessels to ride the bow or stern waves (Williams et al. 1992). Physical presence of vessels, not just ship noise, has been shown to disturb the foraging activity of bottlenose dolphins (Pirodda et al. 2015) and blue whales (Lesage et al. 2017). Sightings of striped dolphin, Risso's dolphin, sperm whale, and Cuvier's beaked whale in the western Mediterranean were negatively correlated with the number of vessels in the area (Campana et al. 2015).

There are few data on the behavioral reactions of beaked whales to vessel noise, though they seem to avoid approaching vessels (e.g., Würsig et al. 1998) or dive for an extended period when approached by a vessel (e.g., Kasuya 1986). Based on a single observation, Aguilar Soto et al. (2006) suggest foraging efficiency of Cuvier's beaked whales may be reduced by close approach of vessels. Tyson et al. (2017) suggested that a juvenile green sea turtle dove during vessel passes and remained still near the sea

floor.

The PEIS concluded that project vessel sounds would not be at levels expected to cause anything more than possible localized and temporary behavioral changes in marine mammals or sea turtles, and would not be expected to result in significant negative effects on individuals or at the population level. In addition, in all oceans of the world, large vessel traffic is currently so prevalent that it is commonly considered a usual source of ambient sound.

Another concern with vessel traffic is the potential for striking marine mammals or sea turtles (e.g., Redfern et al. 2013). Information on vessel strikes is reviewed in § 3.4.4.4, § 3.6.4.4, and § 3.8.4.4 of the PEIS. Wiley et al. (2016) concluded that reducing ship speed is one of the most reliable ways to avoid ship strikes. Similarly, Currie et al. (2017) found a significant decrease in close encounters with humpback whales in the Hawaiian Islands, and therefore reduced likelihood of ship strike, when vessel speeds were below 12.5 kts. However, McKenna et al. (2015) noted the potential absence of lateral avoidance demonstrated by blue whales and perhaps other large whale species to vessels. The PEIS concluded that the risk of collision of seismic vessels or towed/deployed equipment with marine mammals or sea turtles exists but is extremely unlikely, because of the relatively slow operating speed (typically 7–9 km/h) of the vessel during seismic operations, and the generally straight-line movement of the seismic vessel. There has been no history of marine mammal vessel strikes with R/V *Langseth*, or its predecessor, R/V *Maurice Ewing* over the last two decades.

Entanglement of sea turtles in seismic gear is also a concern (Nelms et al. 2016). There have been reports of turtles being trapped and killed between the gaps in tail-buoys offshore from West Africa (Weir 2007); however, these tailbuoys are significantly different than those used on R/V *Langseth*. In April 2011, a dead olive ridley turtle was found in a deflector foil of the seismic gear on R/V *Langseth* during equipment recovery at the conclusion of a survey off Costa Rica, where sea turtles were numerous. Such incidents are possible, but that was the only case of sea turtle entanglement in seismic gear for R/V *Langseth*, which has been conducting seismic surveys since 2008, or for its predecessor, R/V *Maurice Ewing*, during 2003–2007. Towing the seismic equipment during the proposed surveys is not expected to significantly interfere with sea turtle movements, including migration.

4.1.1.4 Mitigation Measures

Several mitigation measures are built into the proposed seismic surveys as an integral part of the planned activity. These measures include the following: ramp ups; typically two, however a minimum of one dedicated observer maintaining a visual watch during all daytime airgun operations; two observers for 30 min before and during ramp ups; PAM during the day and night to complement visual monitoring (unless the system and back-up systems are damaged during operations); and power downs (or if necessary shut downs) when mammals or turtles are detected in or about to enter designated EZ. These mitigation measures are described in § 2.4.4.1 of the PEIS and summarized earlier in this document, in § II (2.1.3). The fact that the airgun array, because of its design, would direct the majority of the energy downward, and less energy laterally, is also an inherent mitigation measure.

Previous and subsequent analysis of the potential impacts takes account of these planned mitigation measures. It would not be meaningful to analyze the effects of the planned activity without mitigation, as the mitigation (and associated monitoring) measures are a basic part of the activity, and would be implemented under the Proposed Action.

4.1.1.5 Potential Numbers of Cetaceans Exposed to Received Sound Levels ≥ 160 dB

All takes would be anticipated to be Level B “takes by harassment” as described in § I, involving

temporary changes in behavior. As required by NMFS, Level A takes have been requested; given the small EZ and the proposed mitigation measures to be applied, injurious takes would not be expected. (However, as noted earlier and in the PEIS, there is no specific information demonstrating that injurious Level A “takes” would occur even in the absence of the planned mitigation measures.) In the sections below, we describe methods to estimate the number of potential exposures to Level A and Level B sound levels and present estimates of the numbers of marine mammals that could be affected during the proposed seismic surveys. The estimates are based on consideration of the number of marine mammals that could be disturbed appreciably by the seismic surveys in the Northeast Pacific Ocean.

The Level B estimates are based on a consideration of the number of marine mammals that could be within the area around the operating airgun array where received levels of sound ≥ 160 dB re $1 \mu\text{Pa}_{\text{rms}}$ are predicted to occur (see Table 1). The estimated numbers are based on the densities (numbers per unit area) of marine mammals expected to occur in the survey area in the absence of a seismic survey. To the extent that marine mammals tend to move away from seismic sources before the sound level reaches the criterion level and tend not to approach an operating airgun array, these estimates likely overestimate the numbers actually exposed to the specified level of sound. The overestimation is expected to be particularly large when dealing with the higher sound level criteria, i.e., the PTS thresholds (Level A), as animals are more likely to move away when received levels are higher. Thus, they are less likely to approach within the PTS threshold radii than they are to approach within the considerably larger ≥ 160 dB (Level B) radius.

Extensive systematic aircraft- and ship-based surveys have been conducted for marine mammals in offshore waters of Oregon and Washington (e.g., Bonnell et al. 1992; Green et al. 1992, 1993; Barlow 1997, 2003; Barlow and Taylor 2001; Calambokidis and Barlow 2004; Barlow and Forney 2007; Forney 2007; Barlow 2010). Ship surveys for cetaceans in slope and offshore waters of Oregon and Washington were conducted by NMFS/SWFSC in 1991, 1993, 1996, 2001, 2005, 2008, and 2014 and synthesized by Barlow (2016); these surveys were conducted up to ~ 556 km from shore from June or August to November or December. Systematic, offshore, at-sea survey data for pinnipeds are more limited; the most comprehensive studies are reported by Bonnell et al. (1992) based on systematic aerial surveys conducted in 1989–1990. Data from the aforementioned sources along with other surveys have been used by SWFSC to conduct spatial habitat modeling in order to derive marine mammal densities for the California Current Ecosystem which are presented by the USN (2018). Here, we use densities from the USN (2018) to calculate takes, as recommended during consultation with NMFS. Where a density range was provided, the maximum value in that range was used for the exposure calculations to be conservative. Although density source information was discussed with NMFS during preparation of the Draft EA, the density information in USN (2018) became available after submission of the Draft EA, which used cetacean densities from Barlow (2016); pinniped densities were based on USN (2010).

Oceanographic conditions, including occasional El Niño and La Niña events, influence the distribution and numbers of marine mammals present in the North Pacific Ocean, resulting in considerable year-to-year variation in the distribution and abundance of many marine mammal species (Forney and Barlow 1998; Buchanan et al. 2001; Ferrero et al. 2002; Philbrick et al. 2003; Escorza-Treviño 2009). Thus, for some species, the densities derived from past surveys may not be representative of the densities that would be encountered during the proposed seismic surveys. However, the approach used here is based on the best available data.

Table 7 gives the densities for each species of marine mammal as reported for offshore waters of the proposed survey area off Oregon/Washington. The estimated numbers of individuals potentially

exposed are based on the 160-dB re 1 $\mu\text{Pa}_{\text{rms}}$ criterion for all marine mammals. It is assumed that marine mammals exposed to airgun sounds that strong could change their behavior sufficiently to be considered “taken by harassment”. Table 8 shows the estimates of the number of marine mammals that potentially could be exposed to ≥ 160 dB re 1 $\mu\text{Pa}_{\text{rms}}$ during the proposed seismic surveys if no animals moved away from the survey vessel (see Appendix B for more details). Except for the fin whale and pinnipeds, the calculated exposures based on these densities are best estimates for the proposed surveys for any time of the year. For the fin whale and pinnipeds, densities for summer/fall were used. For all other species, summer/fall densities were either not available or the same as for other seasons.

For all species, including those for which densities were not available or expected to be low, we have included a *Requested Take Authorization* for at least the mean group size for species where that number was higher than the calculated take. It should be noted that the exposure estimates assume that the proposed surveys would be completed; in fact, the calculated takes **have been increased by 25%** (see below). Thus, the following estimates of the numbers of marine mammals potentially exposed to sounds ≥ 160 dB re 1 $\mu\text{Pa}_{\text{rms}}$ are precautionary and probably overestimate the actual numbers of marine mammals that could be involved.

Consideration should be given to the hypothesis that delphinids are less responsive to airgun sounds than are mysticetes, as referenced in the NSF/USGS PEIS. The 160-dB (rms) criterion currently applied by NMFS, on which the Level B estimates are based, was developed primarily using data from gray and bowhead whales. The estimates of “takes by harassment” of delphinids are thus considered precautionary. Available data suggest that the current use of a 160-dB criterion could be improved upon, as behavioral response might not occur for some percentage of marine mammals exposed to received levels >160 dB, whereas other individuals or groups might respond in a manner considered as “taken” to sound levels <160 dB (NMFS 2013b). It has become evident that the context of an exposure of a marine mammal to sound can affect the animal’s initial response to the sound (NMFS 2013b).

The number of marine mammals that could be exposed to airgun sounds with received levels ≥ 160 dB re 1 $\mu\text{Pa}_{\text{rms}}$ (Level B) for marine mammals on one or more occasions have been estimated using a method required by NMFS for calculating the marine area that would be within the Level B threshold around the operating seismic source, along with the expected density of animals in the area. This method was developed to account in some way for the number of exposures as well as the number of individuals exposed. It involves selecting a seismic trackline(s) that could be surveyed on one day (187 km for the 2-survey; 200 km for the 3-D survey). The area expected to be ensonified on that day was determined by entering the planned survey lines into a MapInfo GIS, using GIS to identify the relevant areas by “drawing” the applicable 160-dB (Table 1) and PTS threshold buffers (Table 2) around each line. The ensonified areas were then multiplied by the number of survey days (16 days for the 3-D survey; 3 days for the 2-D survey) increased by 25%; this is equivalent to adding an additional 25% to the proposed line kilometers (see Appendix C for more details). The approach assumes that no marine mammals would move away or toward the trackline in response to increasing sound levels before the levels reach the specific thresholds as R/V *Langseth* approaches.

Per NMFS requirement, estimates of the numbers of cetaceans and pinnipeds that could be exposed to seismic sounds with received levels equal to Level A thresholds for various hearing groups (see Table 2), if there were no mitigation measures (power downs or shut downs when PSOs observed animals approaching or inside the EZs), are also given in Table 8. Those numbers likely overestimate actual Level A takes because the predicted Level A EZs are small and mitigation measures would further reduce the chances of, if not eliminate, any such takes. In addition, most marine mammals would move away from a sound source before they are exposed to sound levels that could result in a Level A take.

TABLE 7. Densities of marine mammals off Oregon/Washington based on USN (2018). Mean group size from Barlow (2016) unless indicated otherwise. Species in italics are listed under the ESA as *endangered* or *threatened*.

Species	Density (#/1000 km ²)	Mean Group Size
Mysticetes		
<i>North Pacific right whale</i>	–	–
<i>Humpback whale</i>	1.829	2
Minke whale	1.3	1
<i>Sei whale</i>	0.4	2
<i>Fin whale</i>	4.249	2
<i>Blue whale</i>	1.096	1
Odontocetes		
<i>Sperm whale</i>	2.561	6
Pygmy/dwarf sperm whale	1.63	1
Cuvier's beaked whale and Mesoplodonts ¹	7.304	2
Baird's beaked whale	0.82	8
Bottlenose dolphin	0.003	13
Striped dolphin	9.329	109
Short-beaked common dolphin	124.891	286
Pacific white-sided dolphin	17.426	62
Northern right-whale dolphin	39.962	63
Risso's dolphin	7.008	28
False killer whale	–	5 ²
Killer whale	0.92	8
Short-finned pilot whale	0.25	18
Dall's porpoise	43.951	4
Pinnipeds		
Northern fur seal	10.3	–
Northern elephant seal	30.9	–
<i>Guadalupe fur seal</i>	2.9	–

Note: – not available.

¹ Mesoplodonts includes Blainville's, Stejneger's, and Hubbs' beaked whales.

² Mean group size from Mobley et al. (2000).

Dall's porpoise could be more susceptible to exposure to sound levels that exceed the PTS threshold than other marine mammals, as it is known to approach vessels to bowride. However, Level A takes are considered highly unlikely for most marine mammal species that could be encountered in the proposed survey area (see Table 8).

The estimate of the number of marine mammals that could be exposed to seismic sounds with received levels ≥ 160 dB re 1 $\mu\text{Pa}_{\text{rms}}$ in the proposed survey area is 5000 cetaceans and 832 pinnipeds (Table 8). That total includes 248 marine mammals listed as *endangered* or *threatened* under the ESA: 81 fin whales, 35 humpback whales, 8 sei whales, 21 blue whales, 48 sperm whales, and 55 Guadalupe fur seals representing 0.9%, 1.8%, 1.5%, 1.3%, 2.4%, and 0.3% of their regional populations, respectively. In addition, 153 beaked whales could be exposed. Most (75%) of the cetaceans potentially exposed would be delphinids.

TABLE 8. Densities and estimates of the possible numbers of individual marine mammals that could be exposed to Level B and Level A thresholds for various hearing groups during the proposed seismic surveys in the Northeast Pacific Ocean during summer 2019. Density source and number of takes were adjusted from the Draft EA after consultation with NMFS. Species in italics are listed under the ESA as *endangered or threatened*.

Species	Estimated Density ¹ (#/1000 km ²)	Calculated Take, NMFS Daily Method ²		Requested Takes ⁵	% of Pop. ⁶
		Level A ³	Level B ⁴		
LF Cetaceans					
<i>North Pacific right whale</i>	0	0	0	0	0
<i>Humpback whale</i>	1.8	3	32	35	2.1
Minke whale	1.3	2	23	25	3.9
<i>Sei whale</i>	0.4	1	7	8	1.5
<i>Fin whale</i>	4.2	7	74	81	0.9
<i>Blue whale</i>	1.1	2	19	21	0.4
MF Cetaceans					
<i>Sperm whale</i>	2.6	0	48	48	0.9
Cuvier's and <i>Mesoplodont</i> beaked whales	7.3	1	137	138	1.6
Baird's beaked whale	0.8	0	15	15	7.5
Bottlenose dolphin	0.003	0	0	13	0.7
Striped dolphin	9.3	1	175	176	0.5
Short-beaked common	124.9	14	2342	2356	0.1
Pacific white-sided dolphin	17.4	2	327	329	2.9
Northern right-whale dolphin	40.0	4	750	754	3.3
Risso's dolphin	7.0	1	131	132	3.5
False killer whale	0	0	0	5	N.A.
Killer whale ⁷	0.9	0	17	17	3.5
Short-finned pilot whale	0.25	0	5	18 ⁸	2.2
HF Cetaceans					
Pygmy/dwarf sperm whale	1.6	2	29	31	0.8
Dall's porpoise	44.0	43	786	829	4.0
Otariids					
Northern fur seal	10.3	1	193	194	0.2
<i>Guadalupe fur seal</i>	2.9	0	55	55	0.3
Phocids					
Northern elephant seal	30.9	8	575	583	0.9

¹ Densities based on USN (2018); density assumed to be near zero for species not included in USN (2018).

² Take using NMFS daily method for calculating ensonified area: estimated density multiplied by the daily ensonified area on one selected day (187 km for 2-D survey; 200 km for 3-D survey) multiplied by the number of survey days (3 days for the 2-D survey; 16 days for the 3-D survey), times 1.25; see text for more details.

³ Level A takes if there were no mitigation measures.

⁴ Level B takes, based on the 160-dB criterion, excluding exposures to sound levels equivalent to PTS thresholds.

⁵ Requested take authorization is Level A plus Level B calculated takes, used by NMFS as proxy for number of individuals exposed; increased by mean group size (in bold) from Barlow (2016).

⁶ Requested take authorization (Level A + Level B) expressed as % of population off California/Oregon/Washington, Eastern North Pacific, or U.S. stock (see Table 5); N.A. = population size not available.

⁷ Includes individuals from the offshore and West Coast transient stocks.

⁸ Increased to mean group size (2.2% of population).

4.1.1.6 Conclusions for Marine Mammals and Sea Turtles

The proposed seismic surveys would involve towing a 36-airgun array (2-D survey) or an 18-airgun array (3-D survey), which introduce pulsed sounds into the ocean. Routine vessel operations, other than the proposed seismic operations, are conventionally assumed not to affect marine mammals sufficiently to constitute “taking”.

Marine Mammals.—In § 3.6.7, § 3.7.7, and § 3.8.7, the PEIS concluded that airgun operations with implementation of the proposed monitoring and mitigation measures could result in a small number of Level B behavioral effects in some mysticete, odontocete, and pinniped species and that Level A effects were highly unlikely. NMFS required the calculation of and request for potential Level A takes for the Proposed Action (following a different methodology than used in the PEIS and most previous analyses for NSF-funded seismic surveys). For recently NSF-funded seismic surveys, NMFS issued small numbers of Level A take for some marine mammal species for the remote possibility of low-level physiological effects; however, NMFS expected neither mortality nor serious injury of marine mammals to result from the surveys (NMFS 2015b, 2016c,d, 2017b,c).

In this analysis, estimates of the numbers of marine mammals that could be exposed to airgun sounds during the proposed program have been presented, together with the requested “take authorization”. The estimated numbers of animals potentially exposed to sound levels sufficient to cause Level A and/or B harassment are low percentages of the regional population sizes (Table 8). The proposed activities are likely to adversely affect ESA-listed species for which takes are being requested (Table 9). However, the relatively short-term exposures are unlikely to result in any long-term negative consequences for the individuals or their populations.

In decades of seismic surveys carried out by R/V *Langseth* and its predecessor, R/V *Ewing*, PSOs and other crew members have seen no seismic sound-related marine mammal injuries or mortality. Also, actual numbers of animals potentially exposed to sound levels sufficient to cause disturbance (i.e., are considered takes) have almost always been much lower than predicted and authorized takes. For example, during an NSF-funded, ~5000-km, 2-D seismic survey conducted by R/V *Langseth* off the coast of North Carolina in September–October 2014, only 296 cetaceans were observed within the predicted 160-dB zone and potentially taken, representing <2% of the 15,498 takes authorized by NMFS (RPS 2015). During an USGS-funded, ~2700 km, 2-D seismic survey conducted by R/V *Langseth* along the U.S. east coast in August–September 2014, only 3 unidentified dolphins were observed within the predicted 160-dB zone and potentially taken, representing <0.03% of the 11,367 authorized takes (RPS 2014b). Furthermore, as defined, all animals exposed to sound levels >160 dB are Level B ‘takes’ whether or not a behavioral response occurred. The Level B estimates are thought to be conservative; thus, not all animals detected within this threshold distance would be expected to have been exposed to actual sound levels >160 dB.

Sea Turtles.—In § 3.4.7, the PEIS concluded that with implementation of the proposed monitoring and mitigation measures, no significant impacts of airgun operations are likely to sea turtle populations in any of the analysis areas, and that any effects are likely to be limited to short-term behavioral disturbance and short-term localized avoidance of an area of unknown size near the active airguns. In decades of seismic surveys carried out by R/V *Langseth* and its predecessor, R/V *Ewing*, PSOs and other crew members have seen no seismic sound-related sea turtle injuries or mortality. Given the proposed activities, impacts would not be anticipated to be significant or likely to adversely affect ESA-listed sea turtle species (Table 10).

TABLE 9. ESA determination for marine mammal species expected to be encountered during the proposed surveys in the Northeast Pacific Ocean during summer 2019.

Species	ESA Determination		
	No Effect	May Affect – Not Likely to Adversely Affect	May Affect – Likely to Adversely Affect
North Pacific Right Whale		√	
Humpback Whale (Mexico DPS)			√
Sei Whale			√
Fin Whale			√
Blue Whale			√
Sperm Whale			√
Guadalupe Fur Seal			√

TABLE 10. ESA determination for sea turtle species expected to be encountered during the proposed surveys in the Northeast Pacific Ocean during summer 2019.

Species	ESA Determination		
	No Effect	May Affect – Not Likely to Adversely Affect	May Affect – Likely to Adversely Affect
Leatherback Sea Turtle		√	
Green Sea Turtle		√	

4.1.2 Direct Effects on Marine Invertebrates, Fish, and Fisheries, and Their Significance

Effects of seismic sound on marine invertebrates (crustaceans and cephalopods), marine fish, and their fisheries are discussed in § 3.2.4 and § 3.3.4 and Appendix D of the PEIS. Relevant new studies on the effects of sound on marine invertebrates, fish, and fisheries that have been published since the release of the PEIS are summarized below. Although research on the effects of exposure to airgun sound on marine invertebrates and fishes is increasing, many data gaps remain (Hawkins et al. 2015; Carroll et al. 2016), including how particle motion rather than sound pressure levels affect invertebrates and fishes that are exposed to sound (Hawkins and Popper 2017; Popper and Hawkins 2018). In addition, vibrations from sounds may also have an effect on the epibenthos, but sensitivities are largely unknown (Roberts and Elliott 2017). However, activities directly contacting the seabed, such as drilling and pile-driving, would be expected to have a greater impact than sound from an airgun array, although water depth would also factor into the degree of impact.

4.1.2.1 Effects of Sound on Marine Invertebrates

Effects of anthropogenic sounds on marine invertebrates are varied, ranging from no overt reactions to behavioral/physiological responses, injuries, or mortalities (Aguilar de Soto 2016; Carroll et al. 2016; Edmonds et al. 2016; Weilgart 2017b). The available information suggests that invertebrates, particularly crustaceans, may be relatively resilient to airgun sounds (Day et al. 2016a,b). Fewtrell and McCauley (2012) exposed captive squid (*Sepioteuthis australis*) to pulses from a single airgun; the received sound levels ranged from 120–184 dB re 1 $\mu\text{Pa}^2 \cdot \text{s}$ SEL. Increases in alarm responses were seen at SELs >147–151 dB re 1 $\mu\text{Pa}^2 \cdot \text{s}$; the squid were seen to discharge ink or change their swimming pattern or vertical position in the water column.

Solé et al. (2013a,b) exposed four cephalopod species held in tanks to low-frequency (50–400 Hz) sinusoidal wave sweeps (with a 1-s sweep period for 2 h) with received levels of 157 ± 5 dB re $1 \mu\text{Pa}$ and peak levels up to 175 dB re $1 \mu\text{Pa}$. Besides exhibiting startle responses, all four species examined received damage to the statocyst, which is the organ responsible for equilibrium and movement. The animals also showed stressed behavior, decreased activity, and loss of muscle tone (Solé et al. 2013a). To examine the contribution from near-field particle motion from the tank walls on the study, Solé et al. (2017) exposed common cuttlefish (*Sepia officinalis*) in cages in their natural habitat to 1/3 octave bands with frequencies centered at 315 Hz and 400 Hz and levels ranging from 139–141 re $1 \mu\text{Pa}^2$. The study animals still incurred acoustic trauma and injury to statocysts, despite not being held in confined tanks with walls.

When New Zealand scallop (*Pecten novaezelandiae*) larvae were exposed to recorded seismic pulses, significant developmental delays were reported, and 46% of the larvae exhibited body abnormalities; it was suggested that the malformations could be attributable to cumulative exposure (Aguilar de Soto et al. 2013). Their experiment used larvae enclosed in 60-mL flasks suspended in a 2-m diameter by 1.3-m water depth tank and exposed to a playback of seismic sound at a distance of 5–10 cm.

There have been several *in situ* studies that have examined the effects of seismic surveys on scallops. Although most of these studies showed no short-term mortality in scallops (Parry et al. 2002; Harrington et al. 2010; Przeslawski et al. 2016, 2018), one study (Day et al. 2016a,b, 2017) did show adverse effects including an increase in mortality rates. Przeslawski et al. (2016, 2018) studied the potential impacts of an industrial seismic survey on commercial (*Pecten fumatus*) and doughboy (*Mimachlamys asperrima*) scallops. *In situ* monitoring of scallops took place in the Gippsland Basin, Australia, using dredging, and autonomous underwater vehicle deployment before the seismic survey, as well as two, and ten months after the survey. The airgun array used in the study was a single 2530 in³ array made up of 16 airguns operating at 2000 psi with a maximum SEL of 146 dB re $1 \mu\text{Pa}^2 \cdot \text{s}$ at 51 m depth. Overall, there was little to no detectable impact of the seismic survey on scallop health as measured by scallop shell size, adductor muscle diameter, gonad size, or gonad stage (Przeslawski et al. 2016). No scallop mortality related to airgun sounds was detected two or ten months after the seismic survey (Przeslawski et al. 2016, 2018).

Day et al. (2016a,b, 2017) exposed scallops (*P. fumatus*) and egg-bearing female spiny lobsters (*Jasus edwardsi*) at a location 10–12 m below the surface to airgun sounds. The airgun source was started ~1–1.5 km from the study subjects and passed over the animals; thus, the scallops and lobsters were exposed to airgun sounds as close as 5–8 m away and up to 1.5 km from the source. Three different airgun configurations were used in the field: 45 in³, 150 in³ (low pressure), and 150 in³ (high pressure), each with maximum peak-to-peak source levels of 191–213 dB re $1 \mu\text{Pa}$; maximum cumulative SEL source levels were 189–199 dB re $1 \mu\text{Pa}^2 \cdot \text{s}$. Exposure to seismic sound was found to significantly increase mortality in the scallops, especially over a chronic time scale (i.e., months post-exposure), although not beyond naturally occurring rates of mortality (Day et al. 2017). Non-lethal effects were also recorded, including changes in reflex behavior time, other behavioral patterns, haemolymph chemistry, and apparent damage to statocysts (Day et al. 2016b, 2017). However, the scallops were reared in suspended lantern nets rather than their natural environment, which can result in higher mortality rates compared to benthic populations (Yu et al. 2010). The female lobsters were maintained until the eggs hatched; no significant differences were found in the quality or quantity of larvae for control versus exposed subjects, indicating that the embryonic development of spiny lobster was not adversely affected by airgun sounds (Day et al. 2016a,b). No mortalities were reported for control or exposed lobsters (Day et al. 2016a,b).

Fitzgibbon et al. (2017) also examined the impact of airgun exposure on spiny lobster through a companion study to the Day et al. (2016a,b, 2017) studies; the same study site, experimental treatment methodologies, and airgun exposures were used. The objectives of the study were to examine the haemolymph biochemistry and nutritional condition of groups of lobsters over a period of up to 365 days post-airgun exposure. Overall, no mortalities were observed across both the experimental and control groups; however, lobster total haemocyte count decreased by 23–60% for all lobster groups up to 120 days post-airgun exposure in the experimental group when compared to the control group. A lower haemocyte count increases the risk of disease through a lower immunological response. The only other haemolymph parameter that was significantly affected by airgun exposure was the Brix index of haemolymph at 120 and 365 days post-airgun exposure in one of the experiments involving egg-laden females. Other studies conducted in the field have shown no effects on Dungeness crab larvae or snow crab embryos to seismic sounds (Pearson et al. 1994; DFO 2004; Morris et al. 2018).

Payne et al. (2015) undertook two pilot studies which (i) examined the effects of a seismic airgun recording in the laboratory on lobster (*Homerus americanus*) mortality, gross pathology, histopathology, serum biochemistry, and feeding; and (ii) examined prolonged or delayed effects of seismic air gun pulses in the laboratory on lobster mortality, gross pathology, histopathology, and serum biochemistry. For experiment (i), lobsters were exposed to peak-to-peak and root-mean-squared received sound levels of 180 dB re 1 μPa and 171 dB re 1 $\mu\text{Pa}_{\text{rms}}$ respectively. Overall there was no mortality, loss of appendages, or other signs of gross pathology observed in exposed lobster. No differences were observed in haemolymph, feeding, ovary histopathology, or glycogen accumulation in the hepatopancreas. The only observed differences were greater degrees of tubular vacuolation and tubular dilation in the hepatopancreas of the exposed lobsters. For experiment (ii), lobsters were exposed to 20 airgun shots per day for five successive days in a laboratory setting. The peak-to-peak and root-mean-squared received sound levels ranged from ~176–200 dB re 1 μPa and 148–172 dB re 1 $\mu\text{Pa}_{\text{rms}}$, respectively. The lobsters were returned to their aquaria and examined after six months. No differences in mortality, gross pathology, loss of appendages, hepatopancreas/ovary histopathology or glycogen accumulation in the hepatopancreas were observed between exposed and control lobsters. The only observed difference was a slight statistically significant difference for calcium-protein concentration in the haemolymph, with lobsters in the exposed group having a lower concentration than the control group.

Celi et al. (2013) exposed captive red swamp crayfish (*Procambarus clarkia*) to linear sweeps with a frequency range of 0.1–25 kHz and a peak amplitude of 148 dB re 1 $\mu\text{Pa}_{\text{rms}}$ at 12 kHz for 30 min. They found that the noise exposure caused changes in the haemato-immunological parameters (indicating stress) and reduced agonistic behaviors. Wale et al. (2013a,b) showed increased oxygen consumption and effects on feeding and righting behavior of shore crabs when exposed to ship sound playbacks.

McCauley et al. (2017) conducted a 2-day study to examine the potential effects of sound exposure of a 150 in³ airgun on zooplankton off the coast of Tasmania; they concluded that exposure to airgun sound decreased zooplankton abundance compared to control samples, and caused a two- to three-fold increase in adult and larval zooplankton mortality. They observed impacts on the zooplankton as far as 1.2 km from the exposure location – a much greater impact range than previously thought; however, there was no consistent decline in the proportion of dead zooplankton as distance increased and received levels decreased. The conclusions by McCauley et al. (2017) were based on a relatively small number of zooplankton samples, and more replication is required to increase confidence in the study findings. Richardson et al. (2017) presented results of a modeling exercise intended to investigate the impact of exposure to airgun sound on zooplankton over a much larger temporal and spatial scale than that employed by McCauley et al. (2017). The exercise modeled a hypothetical survey over an area 80 km by

36 km during a 35-day period. Richardson et al. (2017) postulated that the decrease in zooplankton abundance observed by McCauley et al. (2017) could have been due to active avoidance behavior by larger zooplankton. The modeling results did indicate that there would be substantial impact on the zooplankton populations at a local spatial scale but not at a large spatial scale; zooplankton biomass recovery within the exposure area and out to 15 km occurred 3 days after completion of the seismic survey.

Leite et al. (2016) reported observing a dead giant squid (*Architeuthis dux*) while undertaking marine mammal observation work aboard a seismic vessel conducting a seismic survey in offshore Brazil. The seismic vessel was operating 48-airgun array with a total volume of 5085 in³. As no further information on the squid could be obtained, it is unknown whether the airgun sounds played a factor in the death of the squid.

Heyward et al. (2018) monitored corals *in situ* before and after exposure to a 3-D seismic survey; the maximum SEL and SPL_{0-pk} were 204 dB re 1 $\mu\text{Pa}^2 \cdot \text{s}$ and 226 dB re 1 μPa . No macroscopic effects on soft tissues or the skeleton were noted days or months after the survey.

4.1.2.2 Effects of Sound on Fish

Potential impacts of exposure to airgun sound on marine fishes have been reviewed by Popper (2009), Popper and Hastings (2009a,b), Fay and Popper (2012), and Weilgart (2017b); they include pathological, physiological, and behavioral effects. Radford et al. (2014) and Putland et al. (2017) noted that masking of key environmental sounds or social signals could also be a potential negative effect from sound. Popper et al. (2014) presented guidelines for seismic sound level thresholds related to potential effects on fish. The effect types discussed include mortality, mortal injury, recoverable injury, temporary threshold shift, masking, and behavioral effects. Seismic sound level thresholds were discussed in relation to fish without swim bladders, fish with swim bladders, and fish eggs and larvae. Hawkins and Popper (2017) cautioned that particle motion as well as sound pressure should be considered when assessing the effects of underwater sound on fishes.

Bui et al. (2013) examined the behavioral responses of Atlantic salmon (*Salmo salar* L.) to light, sound, and surface disturbance events. They reported that the fish showed short-term avoidance responses to the three stimuli. Salmon that were exposed to 12 Hz sounds and/or surface disturbances increased their swimming speeds.

Peña et al. (2013) used an omnidirectional fisheries sonar to determine the effects of a 3-D seismic survey off Vesterålen, northern Norway, on feeding herring (*Clupea harengus*). They reported that herring schools did not react to the seismic survey; no significant changes were detected in swimming speed, swim direction, or school size when the drifting seismic vessel approached the fish from a distance of 27 km to 2 km over a 6-h period. Peña et al. (2013) attributed the lack of response to strong motivation for feeding, the slow approach of the seismic vessel, and an increased tolerance to airgun sounds.

Miller and Cripps (2013) used underwater visual census to examine the effect of a seismic survey on a shallow-water coral reef fish community in Australia. The census took place at six sites on the reef before and after the survey. When the census data collected during the seismic program were combined with historical data, the analyses showed that the seismic survey had no significant effect on the overall abundance or species richness of reef fish. This was in part attributed to the design of the seismic survey (e.g., ≥ 400 m buffer zone around reef), which reduced the impacts of seismic sounds on the fish communities by exposing them to relatively low SELs (< 187 dB re 1 $\mu\text{Pa}^2 \cdot \text{s}$).

Fewtrell and McCauley (2012) exposed pink snapper (*Pagrus auratus*) and trevally (*Pseudocaranx dentex*) to pulses from a single airgun; the received sound levels ranged from 120–184 dB re 1 dB re 1 $\mu\text{Pa}^2 \cdot \text{s}$ SEL. Increases in alarm responses were seen in the fish at SELs >147–151 dB re 1 $\mu\text{Pa}^2 \cdot \text{s}$; the fish swam faster and formed more cohesive groups in response to the airgun sounds.

Hastings and Miksis-Olds (2012) measured the hearing sensitivity of caged reef fish following exposure to a seismic survey in Australia. When the auditory evoked potentials (AEP) were examined for fish that had been in cages as close as 45 m from the pass of the seismic vessel and at water depth of 5 m, there was no evidence of TTS in any of the fish examined, even though the cumulative SELs had reached 190 dB re 1 $\mu\text{Pa}^2 \cdot \text{s}$.

Radford et al. (2016) conducted experiments examining how repeated exposures of different sounds to European seabass (*Dicentrarchus labrax*) can reduce the fishes' response to that sound. They exposed post-larval seabass to playback recordings of seismic survey sound (single strike SEL 144 dB re 1 $\mu\text{Pa}^2 \cdot \text{s}$) in large indoor tanks containing underwater speakers. Their findings indicated that short-term exposure of seismic sound increased the ventilation rate (i.e., opercular beat rate [OBR]) of seabass that were not previously exposed to seismic relative to seabass in controlled, ambient sound conditions. Fish that were reared in tanks that were repeatedly exposed to seismic sound over a 12-week period exhibited a reduced OBR response to that sound type, but fish exposed over the same time period to pile-driving noise displayed a reduced response to both seismic and pile-driving noise. An increased ventilation rate is indicative of greater stress in seabass; however, there was no evidence of mortality or effects on growth of the seabass throughout the 12-week study period.

Przeslawski et al. (2016) studied the potential behavioral impacts of an industrial seismic survey in the Gippsland Basin, Australia, on three shark species: tiger flathead (*Neoplatycephalus richardsoni*), gummy shark (*Mustelus antarcticus*), and swellshark (*Cephaloscyllum laticeps*). Sharks were captured and tagged with acoustic tags before the survey and monitored for movement via acoustic telemetry within the seismic area. The energy source used in the study was a single 2530 in³ array made up of 16 airguns operating at 2000 psi with a maximum SEL of 146 dB re 1 $\mu\text{Pa}^2 \cdot \text{s}$ at 51 m depth. Flathead and gummy sharks were observed to move in and around the acoustic receivers while the airguns in the survey were active; however, most sharks left the study area within 2 days of being tagged. The authors of the study did not attribute this behavior to avoidance, possibly because the study area was relatively small. Overall, there was little conclusive evidence of the seismic survey impacting shark behavior, though flathead shark did show increases in swim speed that was regarded by the authors as a startle response to the airguns operating within the area.

Popper et al. (2016) conducted a study that examined the effects of exposure to seismic airgun sound on caged pallid sturgeon (*Scaphirhynchus albus*) and paddlefish (*Polyodon spathula*); the maximum received peak SPL in this study was 224 dB re 1 μPa . Results of the study indicated no mortality, either during or seven days after exposure, and no statistical differences in effects on body tissues between exposed and control fish.

Andrews et al. (2014) conducted functional genomic studies on the inner ear of Atlantic salmon (*Salmo salar*) that had been exposed to seismic airgun sound. The airguns had a maximum SPL of ~145 dB re 1 $\mu\text{Pa}^2/\text{Hz}$ and the fish were exposed to 50 discharges per trial. The results provided evidence that fish exposed to seismic sound either increased or decreased their expressions of different genes, demonstrating that seismic sound can affect fish on a genetic level.

Sierra-Flores et al. (2015) examined broadcast sound as a short-term stressor in Atlantic cod (*Gadus morhua*) using cortisol as a biomarker. An underwater loudspeaker emitted SPLs ranging from 104–110 dB re 1 $\mu\text{Pa}_{\text{rms}}$. Plasma cortisol levels of fish increased rapidly with sound exposure, returning to baseline levels 20–40 min post-exposure. A second experiment examined the effects of long-term sound exposure on Atlantic cod spawning performance. Tanks were stocked with male and female cod and exposed daily to six noise events, each lasting one hour. The noise exposure had a total SPL of 133 dB re 1 μPa . Cod eggs were collected daily and measured for egg quality parameters as well as egg cortisol content. Total egg volume, floating fraction, egg diameter and egg weight did not appear to be negatively affected by sound exposure. However, fertilization rate and viable egg productivity were reduced by 40% and 50%, respectively, compared with the control group. Mean egg cortisol content was found to be 34% greater in the exposed group as compared to the control group. Elevated cortisol levels inhibit reproductive physiology for males and can result in a greater frequency of larval deformities for spawning females.

4.1.2.3 Effects of Sound on Fisheries

Handegard et al. (2013) examined different exposure metrics to explain the disturbance of seismic surveys on fish. They applied metrics to two experiments in Norwegian waters, during which fish distribution and fisheries were affected by airguns. Even though the disturbance for one experiment was greater, the other appeared to have the stronger SEL, based on a relatively complex propagation model. Handegard et al. (2013) recommended that simple sound propagation models should be avoided and that the use of sound energy metrics like SEL to interpret disturbance effects should be done with caution. In this case, the simplest model (exposures per area) best explained the disturbance effect.

Hovem et al. (2012) used a model to predict the effects of airgun sounds on fish populations. Modeled SELs were compared with empirical data and were then compared with startle response levels for cod. This work suggested that in the future, particular acoustic-biological models could be useful in designing and planning seismic surveys to minimize disturbance to fishing. Their preliminary analyses indicated that seismic surveys should occur at a distance of 5–10 km from fishing areas, in order to minimize potential effects on fishing.

In their introduction, Løkkeborg et al. (2012) described three studies in the 1990s that showed effects on fisheries. Results of a study off Norway in 2009 indicated that fishes reacted to airgun sound based on observed changes in catch rates during seismic shooting; gillnet catches increased during the seismic shooting, likely a result of increased movement of exposed fish, whereas longline catches decreased overall (Løkkeborg et al. 2012).

Streever et al. (2016) completed a Before-After/Control-Impact (BACI) study in the nearshore waters of Prudhoe Bay, Alaska in 2014 which compared fish catch rates during times with and without seismic activity. The air gun arrays used in the geophysical survey had sound pressure levels of 237 dB re 1 μPa_{0-p} , 243 dB re 1 μPa_{p-p} , and 218 dB re 1 $\mu\text{Pa}_{\text{rms}}$. Received SPL_{max} ranged from 107–144 dB re 1 μPa , and received SEL_{cum} ranged from 111–141 dB re 1 $\mu\text{Pa}^2\text{-s}$ for air gun pulses measured by sound recorders at four fyke net locations. They determined that fyke nets closest to air gun activities showed decreases in catch per unit effort (CPUE) while nets further away from the air gun source showed increases in CPUE.

Przeslawski et al. (2016) studied the potential impacts of an industrial seismic survey in the Gippsland Basin, Australia, on catches in the Danish seine and gillnet fishing sectors for 15 fish species. Catch data were examined from 3 years before the seismic survey to six months after completion of the survey in an area 13,000 km^2 . Overall, no significant adverse impacts of the seismic survey on catch rates

were noted. Six of the 15 species were actually found to have increased catch rates.

Paxton et al. (2017) examined the effects of seismic sounds on the distribution and behavior of fish on a temperate reef during a seismic survey conducted in the Atlantic Ocean on the inner continental shelf of North Carolina. Hydrophones were set up near the seismic vessel path to measure SPLs, and a video camera was set up to observe fish abundances and behaviors. Received SPLs were estimated at ~202–230 dB re 1 μ Pa. Overall abundance of fish was lower when undergoing seismic activity as opposed to days when no seismic occurred. Only one fish was observed to exhibit a startle response to the airgun shots. The authors claim that although the study was based on limited data, it contributes evidence that normal fish use of reef ecosystems is reduced when they are impacted by seismic sounds.

Morris et al. (2018) conducted a two-year (2015–2016) BACI study examining the effects of 2-D seismic exploration on catch rates of snow crab (*Chionoecetes opilio*) along the eastern continental slope (Lilly Canyon and Carson Canyon) of the Grand Banks of Newfoundland, Canada. The airgun array used was operated from a commercial seismic exploration vessel; it had a total volume of 4880 in³, horizontal zero-to-peak SPL of 251 dB re 1 μ Pa, and SEL of 229 dB re 1 μ Pa²·s. The closest approach of the survey vessel to the treatment site in 2015 (year 1 of the study) was 1465 m during 5 days of seismic operations; in 2016 (year 2), the vessel passed within 100 m of the treatment site but the exposure lasted only 2 h. Overall, the findings indicated that the sound from the commercial seismic survey did not significantly reduce snow crab catch rates during days or weeks following exposure. Morris et al. (2018) attributed the natural temporal and spatial variations in the marine environment as a greater influence on observed differences in catch rates between control and experimental sites than exposure to seismic survey sounds.

4.1.2.4 Conclusions for Invertebrates, Fish, and Fisheries

The newly available information does not affect the outcome of the effects assessment as presented in the PEIS. The PEIS concluded that there could be changes in behavior and other non-lethal, short-term, temporary impacts, and injurious or mortal impacts on a small number of individuals within a few meters of a high-energy acoustic source, but that there would be no significant impacts of NSF-funded marine seismic research on populations. The PEIS also concluded that seismic surveys could cause temporary, localized reduced fish catch to some species, but that effects on commercial and recreation fisheries would not be significant.

Interactions between the proposed surveys and fishing operations in the proposed survey area are expected to be limited. Two possible conflicts in general are R/V *Langseth*'s streamer entangling with fishing gear and the temporary displacement of fishers from the proposed survey area. Fishing activities could occur within the proposed survey area; however, a safe distance would need to be kept from R/V *Langseth* and the towed seismic equipment. Conflicts would be avoided through communication with the fishing community during the surveys. PSOs would also watch for any impacts the acoustic sources may have on fish during the survey.

Given the proposed activities, impacts would not be anticipated to be significant or likely to adversely affect (including ESA-listed) marine invertebrates, marine fish, and their fisheries (Table 11). In decades of seismic surveys carried out by R/V *Langseth* and its predecessor, R/V *Ewing*, PSOs and other crew members have not observed any seismic sound-related fish or invertebrate injuries or mortality.

TABLE 11. ESA determination for DPSs or ESUs of fish species expected to be encountered during the proposed surveys in the Northeast Pacific Ocean during summer 2019.

Species	ESA Determination		
	No Effect	May Affect – Not Likely to Adversely Affect	May Affect – Likely to Adversely Affect
Bocaccio		√	
Steelhead Trout		√	
Chinook Salmon		√	
Chum Salmon		√	
Coho Salmon		√	
Sockeye Salmon		√	

4.1.3 Direct Effects on Seabirds and Their Significance

The underwater hearing of seabirds (including loons, scaups, gannets, and ducks) has recently been investigated, and the peak hearing sensitivity was found to be between 1500 and 3000 Hz (Crowell 2016). The best sensitivity of underwater hearing for great cormorants was found to be at 2 kHz, with a hearing threshold of 71 dB re 1 $\mu\text{Pa}_{\text{rms}}$ (Hansen et al. 2017). Great cormorants were also found to respond to underwater sounds and may have special adaptations for hearing underwater (Johansen et al. 2016; Hansen et al. 2017). African penguins (*Spheniscus demersus*) outfitted with GPS loggers showed strong avoidance of preferred foraging areas and had to forage further away and increase their foraging effort when a seismic survey was occurring within 100 km of the breeding colony (Pichegru et al. 2017). However, the birds resumed their normal behaviors when seismic operations concluded.

Potential effects of seismic sound and other aspects of seismic operations (collisions, entanglement, and ingestion) on seabirds are discussed in § 3.5.4 of the PEIS. The PEIS concluded that there could be transitory disturbance, but that there would be no significant impacts of NSF-funded marine seismic research on seabirds or their populations. The acoustic source would be powered or shut down in the event an ESA-listed seabird was observed diving or foraging within the designated EZ. Given the proposed activities, impacts would not be anticipated to be significant or likely to adversely affect ESA-listed seabirds (Table 12). In decades of seismic surveys carried out by R/V *Langseth* and its predecessor, the R/V *Ewing*, PSOs and other crew members have seen no seismic sound-related seabird injuries or mortality.

4.1.4 Indirect Effects on Marine Mammals, Sea Turtles, Seabirds and Fish and Their Significance

The proposed seismic operations would not result in any permanent impact on habitats used by marine mammals, sea turtles, seabirds, or fish or to the food sources they use. The main impact issue associated with the proposed activity would be temporarily elevated anthropogenic sound levels and the associated direct effects on these species, as discussed above.

During the proposed seismic surveys, only a small fraction of the available habitat would be ensonified at any given time. Disturbance to fish species and invertebrates would be short-term, and fish would return to their pre-disturbance behavior once the seismic activity ceased. Thus, the proposed surveys would have little impact on the abilities of marine mammals or sea turtles to feed in the area where seismic work is planned. Indirect impacts would not be anticipated to be significant or likely to adversely affect marine mammals, sea turtles, seabirds, or fish.

TABLE 12. ESA determination for seabird species expected to be encountered during the proposed surveys in the Northeast Pacific Ocean during summer 2019.

Species	ESA Determination		
	No Effect	May Affect – Not Likely to Adversely Affect	May Affect – Likely to Adversely Affect
Hawaiian Petrel		√	
Short-tailed Albatross		√	

4.1.5 Cumulative Effects

According to Nowacek et al. (2015), cumulative impacts have a high potential of disturbing marine mammals. Wright and Kyhn (2014) proposed practical management steps to limit cumulative impacts, including minimizing exposure by reducing exposure rates and levels. The results of the cumulative impacts analysis in the PEIS indicated that there would not be any significant cumulative effects to marine resources from the proposed NSF-funded marine seismic research, including the combined use of airguns with MBES, SBP, and acoustic pingers. However, the PEIS also stated that, “A more detailed, cruise-specific cumulative effects analysis would be conducted at the time of the preparation of the cruise-specific EAs, allowing for the identification of other potential activities in the areas of the proposed seismic surveys that may result in cumulative impacts to environmental resources.” Here we focus on activities (e.g., research, vessel traffic, and fisheries) that could impact animals specifically in the proposed survey area.

4.1.5.1 Past and Future Research Activities

The Ocean Observatories Initiative (OOI) hosts an underwater volcanic observatory at the Axial Seamount. In addition to having an active volcano which erupted in 1998, 2011, and 2015, the site has several hydrothermal fields (OOI 2018). Numerous geophysical, chemical, and biological sensors, as well as cameras, are deployed there, which provide real-time information on seismic events via a cabled array (OOI 2018).

In June–August 2004 and August–October 2005, the riserless drilling vessel *JOIDES Resolution* conducted coring off Oregon. During September 2007, July 2009, and September 2017, SIO conducted low-energy seismic surveys for ~5–7 days off the coast of Oregon. During July 2008, UTIG conducted a low-energy seismic survey for ~6 days off the coast of Oregon. Seismic surveys using a 36-airgun array were conducted in the EVH MPA, to the north of the proposed survey area, by R/V *Langseth* during summer 2009, and off the coast of Oregon and Washington during June–July 2012.

During May–June 2018, SIO conducted vibracoring and CHIRP profiles off the Oregon coast, and retrieved seafloor receivers collecting magnetotelluric and passive seismic data offshore Oregon utilizing R/V *Roger Revelle*. SIO deployed geodetic transponders from R/V *Roger Revelle* along the Cascadia subduction zone off Oregon during June 2018, to be retrieved during spring or summer 2020. During June–August 2018, SIO conducted a cabled array survey offshore Oregon using the remote operated vehicle (ROV) *Jason* and R/V *Roger Revelle*. As a component of this survey, a shallow profiler was installed and an ROV was deployed from R/V *Thompson* to turn instruments and/or moorings during July/August 2018 in the vicinity of the proposed survey area. R/V *Sally Ride* was used by SIO to conduct biological sampling to assess mesozooplankton food webs off Oregon and northern California during July 2018, and deploy coastal surface moorings off Oregon and Washington during September–October 2018. R/V *Sally Ride* will not be operating in the vicinity of the proposed survey area during 2019 (current ship schedule established until the end of November 2019). SIO utilized two vessels to conduct sampling for a

primary production study northwest of the proposed survey area during August–September 2018, and collected atmospheric, water column and surficial sediment samples along 152°W from Alaska to Tahiti using R/V *Roger Revelle* during September–October and October–November 2018.

Other research activities may have been conducted in the past or may be conducted in the study area in the future; however, we are not aware of any research activities, in addition to the OOI, that are planned to occur in the proposed project area during summer 2019.

4.1.5.2 Naval Activities

In the summer of 2012, the U.S. Navy conducted a test sponsored by the Naval Sea Systems Command, who is responsible for the research, development, and construction of Navy systems. They tested a towed array with an active acoustic source and a passive receiver. The primary test took place during both a north and south ship transit between San Diego, CA, and Puget Sound in the Pacific Northwest, when the ship was >12 nmi (~22 km) from the coast of the U.S. The Rose Festival Fleet Week occurs annually during October, for which visiting U.S. Navy ships (e.g., destroyers and mine countermeasure ships) and fleet-related elements (e.g., submarines) transit to Portland, Oregon (PRFF 2018). Seafair annually hosts visiting vessels from the U.S. Navy, U.S. Coast Guard and Royal Canadian Navy during Fleet Week and the Boeing Maritime Celebration during July/August on the Seattle, Washington waterfront (Seafair 2018). Navy vessels may transit within or near the proposed survey area during any given year while travelling to west coast Fleet Week ports, depending on a ship's originating location. Other navy activities may have been or may be conducted in this region in the future as this area is included in the western-most part of the U.S. Navy's Northwest Training and Testing Area, which extends up to 250 nmi offshore; however, we are not aware of any specific activities that are planned to occur in the proposed survey area during summer 2019.

4.1.5.3 Vessel Traffic

Several major ports are located on the northwestern coast of the U.S., including Portland, and major shipping lanes originate there. Vessel traffic in the proposed survey area would consist mainly of commercial fishing and cargo vessels. Based on the data available through the Automated Mutual-Assistance Vessel Rescue (AMVER) system managed by the U.S. Coast Guard (USCG), four or fewer cargo vessels travelled through the proposed survey area during the July–September 2018 (USCG 2018). Various types of vessels were in the general vicinity of the proposed survey area when MarineTraffic (2018) was accessed on 19 November 2018, including cargo vessels (11) and tankers (3). The total transit time by R/V *Langseth* (2 days) would be minimal relative to the number of other vessels operating in the proposed survey area during summer 2019. Thus, the combination of R/V *Langseth*'s operations with the existing shipping operations is expected to produce only a negligible increase in overall ship disturbance effects on marine mammals.

4.1.5.4 Fisheries Interactions

The commercial fisheries in the region are described in § III. The primary contributions of fishing to potential cumulative impacts on marine mammals and sea turtles involve direct and indirect removal of prey items, sound produced during fishing activities, and potential entanglement (Reeves et al. 2003).

Marine mammals.—According to Lewison et al. (2014), the northwest coast of the U.S. has relatively high bycatch rates for marine mammals. Between 1990 and 1996, an average of 456 cetaceans and 160 pinnipeds were killed or seriously injured per year in the California/Oregon driftnet fishery. As a result of regulatory action to reduce cetacean bycatch in 1997, bycatch was reduced to a yearly average of 105 cetaceans (8 odontocete species and fin, minke, and gray whales) and 77 pinnipeds (California sea

lion and northern elephant seal) during the 1997–2006 period (Moore et al. 2009). In 2009, based on observed bycatch, the estimated total bycatch in the California/Oregon large-mesh drift gillnet fishery for thresher sharks and swordfish was 7 short-beaked common dolphins, 15 Pacific white-sided dolphins, and 37 California sea lions (Carretta and Enriquez 2010).

Before 2000, high bycatch of harbor porpoises, southern sea otters, and pinnipeds (California sea lion, harbor seals, and elephant seals) occurred in the set gillnet fishery for California halibut. The bycatch likely led to the decline of the harbor porpoise. Restrictions applied between 2000 and 2002 effectively closed most of the fishery (Moore et al. 2009).

Three fisheries had marine mammal takes in the non-Pacific hake groundfish fisheries from 2002 to 2005 (NMFS 2008). An estimated 250 marine mammals were killed in the limited-entry bottom trawl fishery; bycatch estimates included 227.6 California sea lions, 11.5 Steller sea lions, 7.5 Pacific white-sided dolphins, and 3.1 harbor porpoises (NMFS 2008). Bycatch in the limited-entry sablefish fishery was estimated at 29 California sea lions. Eight California sea lions were also killed in the non-sablefish endorsed fishery during the same period (NMFS 2008). A number of pinnipeds were also caught in the west coast Pacific hake fishery; estimated bycatch for 2002–2006 included 2.5 harbor seals, 8.3 Steller sea lions, 6.9 California sea lions, and 3.4 elephant seals (NMFS 2008). During 2007–2009, bycatch totals for the U.S. west coast groundfish fishery included 19 California sea lions, 12 Steller sea lions, 12 northern elephant seals, 5 harbor seals, 1 Risso’s dolphin, 1 bottlenose dolphin, and 1 sperm whale (Jannot et al. 2011). The extent of bycatch is unknown in some fisheries that receive little or no observer coverage. In 2005, ~87 short-beaked common dolphins were killed in squid purse seines; an estimated 5196 other marine mammals were caught but released alive across all other observed California purse seine fisheries (Carretta and Enriquez 2006). In 2005, the bycatch for the Northwest Region (including Oregon) for the sablefish-endorsed fixed gear, groundfish bottom trawl, and mid-water hake trawl fisheries was estimated at 37 animals, including 33.7 California sea lions, 2.4 Steller sea lions, and 1.2 harbor seals (NMFS 2011). From 2010–2014, Carretta et al. (2016b) reported 85 large whales and 116 small cetaceans entangled in fishing gear for the U.S. west coast; there were 180 cases of pinniped injuries and mortalities in the hook and line fishery.

Sea turtles.—According to Lewison et al. (2014), the northwest coast of the U.S. has relatively low bycatch rates for sea turtles. Finkbeiner et al. (2011) reported that between 1990 and 2007, the annual mean bycatch for sea turtles in the California/Oregon driftnet fishery was 30 individuals before regulations came into effect, and <10 after regulations were put in place. Moore et al. (2009) reported that an average of 14 leatherbacks were killed annually in the California/Oregon drift gillnet fishery before regulations were implemented to reduce bycatch in 1997 and 2001. There was no bycatch reported for 2005 (NMFS 2011). One sea turtle (a leatherback in 2008) was killed or injured in the west coast groundfish fishery in 2002–2009 off California (Jannot et al. 2011). Carretta and Enriquez (2010) reported one leatherback caught and released alive in 2009.

Seabirds.—According to Lewison et al. (2014), the northwest coast of the U.S. has relatively low bycatch rates for seabirds. Net fisheries for salmon in Puget Sound have killed thousands of birds annually, mostly murre and auklets (Moore et al. 2009). Annual seabird bycatch in the set net fishery for California halibut during 1990–2001 ranged from 308 to 3259; most bycatch consisted of common murre, loons, grebes, and cormorants (Moore et al. 2009). Closure of the central California fishery in depths <110 m in 2002 reduced bycatch to an estimated 61 seabirds in 2003 (Moore et al. 2009). The estimated take of seabirds in the non-Pacific hake fisheries during 2002–2005 totaled 575, half of which were common murre. Other species caught included Leach’s storm petrel, Brandt’s cormorant, black-footed albatross, western gull, and brown pelican (NMFS 2008). Jannot et al. (2011) reported takes

of 11 seabird species in the west coast groundfish fishery during 2002–2009, including marbled murrelets and short-tailed albatross; in 2009, northern fulmars made up most of the bycatch. The estimated take of seabirds in the Pacific hake fisheries during the same period was 50 birds, including seven black-footed albatrosses, five common murrelets, 23 northern fulmars, two sooty shearwaters, and 13 unidentified seabirds (NMFS 2008). In 2005, the bycatch for the Northwest Region (including Oregon) was estimated at 106 birds for the west coast groundfish limited entry non-trawl, groundfish bottom trawl, and mid-water hake trawl fisheries, including 58.8 black-footed albatross, 35.6 brown pelicans, 3.8 gulls, 2 sooty shearwaters, 2 northern fulmars, 2 common murrelets, and 2 unidentified seabirds (NMFS 2011).

4.1.6 Unavoidable Impacts

Unavoidable impacts to the species of marine mammals and turtles occurring in the proposed survey area would be limited to short-term, localized changes in behavior of individuals. For marine mammals, some of the changes in behavior may be considered to fall within the MMPA definition of “Level B Harassment” (behavioral disturbance; no serious injury or mortality). TTS, if it occurs, would be limited to a few individuals, is a temporary phenomenon that does not involve injury, and is unlikely to have long term consequences for the few individuals involved. No long-term or significant impacts would be expected on any of these individual marine mammals or turtles, or on the populations to which they belong; NMFS, however, requires NSF to request Level A takes. Effects on recruitment or survival would be expected to be (at most) negligible.

4.1.7 Coordination with Other Agencies and Processes

This Final EA was prepared by LGL on behalf of L-DEO and NSF pursuant to Executive Order 12114. Potential impacts to marine mammals, endangered species, and critical habitat were assessed in the document. The Draft EA was used to support the ESA Section 7 consultation process with NMFS and USFWS, and was also used as supporting documentation for an IHA application submitted by L-DEO, on behalf of itself, NSF, UTIG, UNR, SIO, to NMFS, under the U.S. MMPA, for “taking by harassment” (disturbance) of small numbers of marine mammals, for the proposed seismic surveys.

NSF coordinated with NMFS to complete the Final EA prior to issuance of an IHA and Biological Opinion/ITS to accommodate NMFS’ need to adopt NSF’s Final EA as part of the process associated with issuing authorizations. NSF had enhanced coordination with NMFS throughout the IHA and ESA consultation processes to facilitate this streamlined approach.

(a) Endangered Species Act (ESA)

The Draft EA was used during the ESA Section 7 consultation process with NMFS and USFWS. On 11 April 2019, NSF submitted a letter of concurrence request to USFWS that the proposed activity may affect but was not likely to adversely affect the *endangered* Hawaiian petrel and short-tailed albatross. Mitigation measures for these species would include power downs/shut downs for diving or foraging ESA-listed seabirds within the exclusion zones. Based on consultation discussions with USFWS, NSF anticipates receiving a letter of concurrence in advance of the proposed activity. On 21 December 2018, NSF submitted a formal ESA Section 7 consultation request, including the Draft EA, to NMFS for the proposed activity. As previously noted, NSF had enhanced coordination with NMFS during the consultation process. Based on this enhanced coordination, NSF anticipates that a Biological Opinion and ITS will be issued for the proposed activity. As part of its decision-making process for the Proposed Action, NSF will take into consideration the Biological Opinion and ITS issued by NMFS, findings by USFWS, and the results of the entire environmental review process.

(b) Marine Mammal Protection Act (MMPA)

The Draft EA was also used as supporting documentation for an IHA application submitted on 21 December 2018 by L-DEO on behalf of itself, NSF, and the researchers, to NMFS, under the U.S. MMPA, for “taking by harassment” (disturbance) of small numbers of marine mammals during the proposed seismic surveys. NMFS issued the Federal Register a notice of intent to issue an IHA for the survey and a 30-day public comment period. NMFS will consider any comments received and provide responses as required per the IHA process. As previously noted, NSF had enhanced coordination with NMFS during the IHA application process. Based on this enhanced coordination, NSF anticipates that an IHA will be issued for the proposed activity. As part of its decision-making process for the Proposed Action, NSF will take into consideration the IHA issued by NMFS and the results of the entire environmental review process.

4.2 No Action Alternative

An alternative to conducting the proposed activity is the “No Action” Alternative, i.e., do not issue an IHA and do not conduct the operations. If the research were not conducted, the “No Action” alternative would result in no disturbance to marine mammals or sea turtles attributable to the proposed activity; however, valuable data about the marine environment would be lost. Research that would contribute to our understanding of the nature of the magmatic reservoirs, and adding to the comprehensive assessment of geohazards for the Pacific Northwest, such as earthquake, tsunami, and submarine landslide hazards, would not be collected. The No Action Alternative would not meet the purpose and need for the proposed activity.

V LIST OF PREPARERS

LGL Ltd., environmental research associates

Meike Holst, M.Sc., Sidney, BC*
Sarah Penney-Belbin, M.Sc., St. John's, NL*
Susan Dufault, M.Sc., Bryan, TX*
Darren Ireland, M.Sc., Bryan, TX
Nathan Hentze, M.Sc., Sidney, BC
Colin Jones, B.Sc., St. John's, NL
W. John Richardson, Ph.D., King City, ON

Lamont-Doherty Earth Observatory

Anne Bécel, Ph.D., Palisades, NY
Sean Higgins, Ph.D., Palisades, NY

National Science Foundation

Holly E. Smith, M.A., Arlington, VA

* Principal preparers of this specific document. Others listed above contributed to a lesser extent, or contributed substantially to previous related documents from which material has been excerpted.

VI LITERATURE CITED

- Aarts, G., A.M. von Benda-Beckmann, K. Lucke, H.Ö. Sertlek, R. Van Bemmelen, S.C. Geelhoed, S. Brasseur, M. Scheidat, F.P.A. Lam, H. Slabbekoorn, and R. Kirkwood. 2016. Harbour porpoise movement strategy affects cumulative number of animals acoustically exposed to underwater explosions. **Mar. Ecol. Prog. Ser.** 557:261-275.
- Acevedo, A. and M.A. Smultea. 1995. First records of humpback whales including calves at Golfo Dulce and Isla del Coco, Costa Rica, suggesting geographical overlap of northern and southern hemisphere populations. **Mar. Mamm. Sci.** 11(4):554-560.
- Acosta, A., N. Nino-Rodriguez, M.C. Yepes, and O. Boisseau. 2017. Mitigation provisions to be implemented for marine seismic surveying in Latin America: a review based on fish and cetaceans. **Aquat. Biol.** 199-216.
- Adams, J., J. Felis, J.W. Mason, and J.Y. Takekawa. 2014. Pacific Continental Shelf Environmental Assessment (PaCSEA): aerial seabird and marine mammal surveys off northern California, Oregon, and Washington, 2011-2012. U.S. Dept. of the Interior, Bureau of Ocean Energy Management, Pacific OCS Region, Camarillo, CA. OCS Study BOEM 2014-003. 266 p.
- Aguilar, A. 2009. Fin whale *Balaenoptera physalus*. p. 433-437 In: W.F. Perrin, B. Würsig, and J.G.M. Thewissen (eds.), Encyclopedia of marine mammals, 2nd edit. Academic Press, San Diego, CA. 1316 p.
- Aguilar de Soto, N. 2016. Peer-reviewed studies on the effects of anthropogenic noise on marine invertebrates: from scallop larvae to giant squid. p. 17-26 In: The effects of noise on aquatic life II, Springer, New York, NY. 1292 p.
- Aguilar de Soto, N., N. Delorme, J. Atkins, S. Howard, J. Williams, and M. Johnson. 2013. Anthropogenic noise causes body malformations and delays development in marine larvae. **Sci. Rep.** 3:2831. <http://dx.doi.org/doi:10.1038/srep02831>.
- Aguilar Soto, N., M. Johnson, P.T. Madsen, P.L. Tyack, A. Bocconcelli, and J.F. Borsani. 2006. Does intense ship noise disrupt foraging in deep-diving Cuvier's beaked whales (*Ziphius cavirostris*)? **Mar. Mamm. Sci.** 22(3):690-699.
- Allen, G.M. 1942. Extinct and vanishing mammals of the Western Hemisphere with the marine species of all oceans. **Spec. Publ. Am. Comm. Int. Wildl. Protection**, No.11. 620 p.
- Anderwald, P., A. Brandecker, M. Coleman, C. Collins, H. Denniston, M.D. Haberlin, M. O'Donovan, R. Pinfield, F. Visser, and L. Walshe. 2013. Displacement responses of a mysticete, an odontocete, and a phocid seal to construction-related vessel traffic. **Endang. Species Res.** 21(3):231-240.
- Andrews, C.D., J.F. Payne, and M.L. Rise. 2014. Identification of a gene set to evaluate the potential effects of loud sounds from seismic surveys on the ears of fishes: a study with *Salmo salar*. **J. Fish Biol.** 84(6):1793-1819.
- Antonelis, G.A. and C.H. Fiscus. 1980. The pinnipeds of the California current. **Calif. Coop. Oceanogr. Fish. Invest. Rep.** 21:68-78.
- Archer, F.I. 2009. Striped dolphin *Stenella coeruleoalba*. p. 1127-1129 In: W.F. Perrin, B. Würsig, and J.G.M. Thewissen (eds.), Encyclopedia of marine mammals, 2nd edit. Academic Press, San Diego, CA. 1316 p.
- Arnbom, T. and H. Whitehead. 1989. Observations on the composition and behaviour of groups of female sperm whale near the Galápagos Islands. **Can. J. Zool.** 67(1):1-7.
- Atkinson, S., D. Crocker, D. Houser, and K. Mashburn. 2015. Stress physiology in marine mammals: How well do they fit the terrestrial model? **J. Comp. Physiol. B** 185(5):463-486. <http://dx.doi.org/doi:10.1007/s00360-015-0901-0>.

- Aurioles-Gamboa, D., F. Elorriaga-Verplancken, and C.J. Hernandez-Camacho. 2010. The current population status of Guadalupe fur seal (*Arctocephalus townsendi*) on the San Benito Islands, Mexico. **Mar. Mamm. Sci.** 26(2):402-408.
- Azzara, A.J., W.M. von Zharen, and J.J. Newcomb. 2013. Mixed-methods analytic approach for determining potential impacts of vessel noise on sperm whale click behavior. **J. Acoust. Soc. Am.** 134(6):4566-4574.
- Bailey, H., S.R. Benson, G.L. Shillinger, S.J. Bograd, P.H. Dutton, S.A. Eckert, S.J. Morreale, F.V. Paladino, T. Eguchi, D.G. Foley, B.A. Block, R. Piedra, C. Hitipeuw, R.F. Tapilatu, and J.R. Spotila. 2012. Identification of distinct movement patterns in Pacific leatherback turtle populations influenced by ocean conditions. **Ecol. Appl.** 22(3):735-747.
- Bailey, H., B.R. Mate, D.M. Palacios, L. Irvine, S.J. Bograd, and D.P. Costa. 2009. Behavioural estimation of blue whale movements in the Northeast Pacific from state-space model analysis of satellite tracks. **Endang. Spec. Res.** 10:93-106.
- 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 Pap. SC/58/E35. Int. Whal. Comm., Cambridge, UK. 13 p.
- Baird, R.W. 2009. Risso's dolphin. p. 975-976 *In*: W.F. Perrin, B. Würsig, and J.G.M. Thewissen (eds.), *Encyclopedia of marine mammals*, 2nd edit. Academic Press, San Diego, CA. 1316 p.
- Baker, C.S. and L.M. Herman. 1989. Behavioral responses of summering humpback whales to vessel traffic: experimental and opportunistic observations. NPS-NR-TRS-89-01. Rep. from Kewalo Basin Mar. Mamm. Lab., Univ. Hawaii, Honolulu, HI, for U.S. Natl. Park Serv., Anchorage, AK. 50 p. NTIS PB90-198409.
- Baker, C.S., L.M. Herman, B.G. Bays, and W.F. Stifel. 1982. The impact of vessel traffic on the behavior of humpback whales in southeast Alaska. Rep. from Kewalo Basin Mar. Mamm. Lab., Honolulu, HI, for U.S. Natl. Mar. Fish. Serv., Seattle, WA. 78 p.
- Baker, C.S., L.M. Herman, B.G. Bays, and G.B. Bauer. 1983. The impact of vessel traffic on the behavior of humpback whales in southeast Alaska: 1982 season. Rep. from Kewalo Basin Mar. Mamm. Lab., Honolulu, HI, for U.S. Nat. Mar. Mamm. Lab., Seattle, WA. 30 p. + fig., tables.
- Baker, C.S., A. Perry, J.L. Bannister, M.T. Weinrich, R.B. Abernethy, J. Calambokidis, J. Lien, R.H. Lambertsen, J. Urbán Ramirez, O. Vasquez, P.J. Clapham, A. Alling, S.J. O'Brien, and S.R. Palumbi. 1993. Abundant mitochondrial DNA variation and world-wide population structure in humpback whales. **Proc. Nat. Acad. Sci. USA** 90:8239-8243.
- Banfield, A.W.F. 1974. *The mammals of Canada*. Univ. Toronto Press. 438 p.
- Barlow, J. 1994. Recent information on the status of large whales in California waters (Vol. 203). Nat. Mar. Fish. Serv., Southwest Fish. Sci. Center.
- Barlow, J. 1995. The abundance of cetaceans in California waters: Part I. Ship surveys in summer and fall of 1991. **Fish. Bull.** 93(1):1-14.
- Barlow, J. 1997. Preliminary estimates of cetacean abundance off California, Oregon and Washington based on a 1996 ship survey and comparisons of passing and closing modes. Admin. Rep. LJ-97-11. Nat. Mar. Fish. Serv., Southwest Fish. Sci. Center, La Jolla, CA. 31 p.
- Barlow, J. 2003. Preliminary estimates of the abundance of cetaceans along the U.S. west coast: 1991-2001. Admin. Rep. LJ-03-03. Nat. Mar. Fish. Serv., Southwest Fish. Sci. Center, La Jolla, CA. 31 p.
- Barlow, J. 2010. Cetacean abundance in the California Current estimated from a 2008 ship-based line-transect survey. NOAA Tech. Memo. NMFS NOAA-TM-NMFS-SWFSC-456. U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, and Southwest Fisheries Science Centre. 19 p.

- Barlow, J. 2016. Cetacean abundance in the California Current estimated from ship-based line-transect surveys in 1991-2014. NOAA Admin. Rep. LJ-16-01. 31 p. + appendix.
- Barlow, J. and K.A. Forney. 2007. Abundance and density of cetaceans in the California Current ecosystem. **Fish. Bull.** 105:509-526.
- Barlow, J. and R. Gisiner. 2006. Mitigating, monitoring and assessing the effects of anthropogenic sound on beaked whales. **J. Cetac. Res. Manage.** 7(3):239-249.
- Barlow, J. and B. Taylor. 2005. Estimates of sperm whale abundance Barlow, J. and K.A. Forney. 2007. Abundance and population density of cetaceans in the California Current ecosystem. **Fish. Bull.** 105:509-526.
- Barlow, J., K.A. Forney, P.S. Hill, R.L. Brownell, Jr., J.V. Carretta, D.P. DeMaster, F. Julian, M.S. Lowry, T. Ragen, and R.R. Reeves. 1997. U.S. Pacific marine mammal stock assessments: 1996. NOAA Tech. Memo. NMFS-SWFSC-248. Nat. Mar. Fish. Serv., Southwest Fish. Sci. Center, La Jolla, CA. 223 p.
- Barros, N.B., D.A. Duffield, P.H. Ostrom, D.K. Odell, and V.R. Cornish. 1998. Nearshore vs. offshore ecotype differentiation of *Kogia breviceps* and *K. simus* based on hemoglobin, morphometric and dietary analyses. Abstr. World Mar. Mamm. Sci. Conf., Monaco, 20–24 Jan. 1998.
- Barry, S.B., A.C. Cucknell, and N. Clark. 2012. A direct comparison of bottlenose dolphin and common dolphin behaviour during seismic surveys when airguns are and are not being utilised. p. 273-276 *In*: A.N. Popper and A. Hawkins (eds.), The effects of noise on aquatic life. Springer, New York, NY. 695 p.
- Baumann-Pickering, S., M.A. Roch, R.L. Brownell, Jr., A.E. Simonis, M.A. McDonald, A. Solsona-Berga, E.M. Oleson, S.M. Wiggins, and J.A. Hildebrand. 2014. Spatio-temporal patterns of beaked whale echolocation signals in the North Pacific. **PLoS One** 9(1):e86072. <http://dx.doi.org/doi:10.1371/journal.pone.0086072>.
- BCBRC (British Columbia Bird Records Committee). 2018. BC Bird Records Committee Sightings Database, February 2018. Accessed November 2018 at <https://bcfo.ca/bc-bird-records-committee-sightings-database/>.
- Becker, E.A. 2007. Predicting seasonal patterns of California cetacean density based on remotely sensed environmental data. Ph.D. Thesis, Univ. Calif. Santa Barbara, Santa Barbara, CA. 284 p.
- Becker, E.A., K.A. Forney, M.C. Ferguson, J. Barlow, and J.V. Redfern. 2012. Predictive modeling of cetacean densities in the California Current ecosystem based on summer/fall ship surveys in 1991-2008. NOAA Tech. Memo. NOAA-TM-NMFS-SWFSC-499. Nat. Mar. Fish. Service, Southwest Fish. Sci. Centre. 45 p.
- Becker, E.A., K.A. Forney, D.G. Foley, R.C. Smith, T.J. Moore, and J. Barlow. 2014. Predicting seasonal density patterns of California cetaceans based on habitat models. **Endang. Species Res.** 23: 1-22.
- Belcher, R.L. and T.E. Lee, Jr. 2002. *Arctocephalus townsendi*. **Mamm. Species** 700:1-5.
- Benson, S.R., P.H. Dutton, C. Hitipeuw, Y. Thebu, Y. Bakarbesy, C. Sorondanya, N. Tangkepayung, and D. Parker. 2008. Post-nesting movements of leatherbacks from Jamursba Medi, Papua, Indonesia: linking local conservation with international threats. NOAA Tech. Memo. NMFS-SEFSC-567. 14 p.
- Benson, S.R., T. Eguchi, D. G. Foley, K. A. Forney, H. Bailey, C. Hitipeuw, B.P. Samber, R. F. Tapilatu, V. Rei, P. Ramohia, J. Pita, and P.H. Dutton. 2011. Large-scale movements and high-use areas of western Pacific leatherback turtles, *Dermochelys coriacea*. **Ecosphere** 2(7):1-27.
- Bernstein, L. 2013. The Washington Post: health, science, and environment. Panel links underwater mapping sonar to whale stranding for first time. Published 6 October 2013. Accessed in December 2015 at http://www.washingtonpost.com/national/health-science/panel-links-underwater-mapping-sonar-to-whale-stranding-for-first-time/2013/10/06/52510204-2e8e-11e3-bbed-a8a60c601153_story.html.
- Best, P.B. 1979. Social organization in sperm whales, *Physeter macrocephalus*. p. 227-289 *In*: H.E. Winn and B.L. Olla (eds.), Behavior of marine animals, Vol. 3. Plenum, New York, NY.

- Bettridge, S., C.S. Baker, J. Barlow, P.J. Clapham, M. Ford, D. Gouveia, D.K. Mattila, R.M. Pace, III, P.E. Rosel, G.K. Silber, and P.R. Wade. 2015. Status review of the humpback whale (*Megaptera novaeangliae*) under the Endangered Species Act. NOAA Tech. Memo. NMFS-SWFSC-540. Nat. Mar. Fish. Service, Southwest Fish. Sci. Center, La Jolla, CA. 240 p.
- BirdLife International. 2018a. Species factsheet: *Phoebastria albatrus*. Accessed on 15 November 2018 at <http://www.birdlife.org>.
- BirdLife International. 2018b. Species factsheet: *Pterodroma sandwichensis*. Accessed on 15 November 2018 at <http://www.birdlife.org>.
- Bittencourt, L., I.M.S. Lima, L.G. Andrade, R.R. Carvalho, T.L. Bisi, J. Lailson-Brito, Jr., and A.F. Azevedo. 2016. Underwater noise in an impacted environment can affect Guiana dolphin communication. **Mar. Poll. Bull.** <https://doi.org/10.1016/j.marpolbul.2016.10.037>.
- Blackwell, S.B., C.S. Nations, T.L. McDonald, C.R. Greene, Jr., A.M. Thode, M. Guerra, and A.M. Macrander. 2013. Effects of airgun sounds on bowhead whale calling rates in the Alaskan Beaufort Sea. **Mar. Mamm. Sci.** <http://dx.doi.org/doi:10.1111/mms.12001>.
- Blackwell, S.B., C.S. Nations, T.L. McDonald, A.M. Thode, D. Mathias, K.H. Kim, C.R. Greene, Jr., and A.M. Macrander. 2015. Effects of airgun sounds on bowhead whale calling rates: evidence for two behavioral thresholds. **PLoS ONE** 10(6):e0125720. <http://dx.doi.org/doi:10.1371/journal.pone.0125720>.
- Blair, H.B., N.D. Merchant, A.S. Friedlaender, D.N. Wiley, and S.E. Parks. 2016. Evidence for ship noise impacts on humpback whale foraging behaviour. **Biol. Lett.** 12:20160005.
- Block, B.A., I.D. Jonsen, S.J. Jorgensen, A.J. Winship, S.A. Shaffer, S.J. Bograd, E.L. Hazen, D.G. Foley, G.A. Breed, A.-L. Harrison, J.E. Ganong, A. Swithenbank, M. Castleton, H. Dewar, B.R. Mate, G.L. Shillinger, K.M. Schaefer, S.R. Benson, M.J. Weise, R.W. Henry, and D.P. Costa. 2011. Tracking apex marine predator movements in a dynamic ocean. **Nature** 475(7354):86-90. <http://dx.doi.org/doi:10.1038/nature10082>.
- Bonnell, M.L., C.E. Bowlby, and G.A. Green. 1992. Pinniped distribution and abundance off Oregon and Washington, 1989–1990. In: J.J. Brueggeman (ed.), Oregon and Washington marine mammal and seabird surveys. Minerals Management Service Contract Report 14-12-0001-30426.
- Bowlby, C.E., G.A. Green, and M.L. Bonnell. 1994. Observations of leatherback turtles offshore of Washington and Oregon. **Northw. Nat.** 75:33-35.
- Boyer, C. 2017. U.S. Fish and Wildlife teams up with SeaWorld to rehabilitate rescued sea turtles in Oregon. Article in January 12, 2017 Eugene Weekly, accessed on 7 March 2017 at <http://www.eugeneweekly.com/20170112/news-features>.
- Branstetter, B.K., J.S. Trickey, and H. Aihara. J.J. Finneran, and T.R. Liberman. 2013. Time and frequency metrics related to auditory masking of a 10 kHz tone in bottlenose dolphins (*Tursiops truncatus*). **J. Acoust. Soc. Am.** 134(6):4556-4565.
- Branstetter, B.K., K.L. Bakhtiari, J.S. Trickey, and J.J. Finneran. 2016. Hearing mechanisms and noise metrics related to auditory masking in bottlenose dolphins (*Tursiops truncatus*). p. 109-116 In: A.N. Popper and A. Hawkins (eds.), The effects of noise on aquatic life II. Springer, New York, NY. 1292 p.
- Breitzke, M. and T. Bohlen. 2010. Modelling sound propagation in the Southern Ocean to estimate the acoustic impact of seismic research surveys on marine mammals. **Geophys. J. Int.** 181(2):818-846.
- Britten, L. 2018. 'Son of the blob': unseasonably warm weather creating new anomaly off B.C. coast. CBC News, 18 October 2018. Accessed on 13 November 2018 at <https://www.cbc.ca/news/canada/british-columbia/blob-pacific-ocean-bc-1.4867674>.
- Brodeur, R.D., M.E. Hunsicker, A. Hann, and T.W. Miller. 2018. Effects of warming ocean conditions on feeding ecology of small pelagic fishes in a coastal upwelling ecosystem: a shift to gelatinous food sources. **Mar. Ecol. Prog. Ser.** (Advance View). <https://doi.org/10.3354/meps12497>. 15 p.

- Bröker, K., J. Durinck, C. Vanman, and B. Martin. 2013. Monitoring of marine mammals and the sound scape during a seismic survey in two license blocks in the Baffin Bay, West Greenland, in 2012. p. 32 *In: Abstr. 20th Bienn. Conf. Biol. Mar. Mamm.*, 9–13 December 2013, Dunedin, New Zealand. 233 p.
- Bröker, K., G. Gailey, J. Muir, and R. Racca. 2015. Monitoring and impact mitigation during a 4D seismic survey near a population of gray whales off Sakhalin Island, Russia. **Endang. Species Res.** 28:187-208.
- Brownell, R.L., W.A. Walker, and K.A. Forney. 1999. Pacific white-sided dolphin *Lagenorhynchus obliquidens* (Gray, 1828). p. 57-84 *In: S.H. Ridgway and S.R. Harrison (eds.), Handbook of marine mammals, Vol. 6: The second book of dolphins and porpoises.* Academic Press, London, UK. 486 p.
- Brownell, R.L., P.J. Clapham, T. Miyashita, and T. Kasuya. 2001. Conservation status of North Pacific right whales. **J. Cetacean Res. Manage.** (Special Issue 2):269-286.
- Brueggeman, J.J. (ed.). 1991. Oregon and Washington marine mammal and seabird surveys. OCS Study MMS 91-000 (Contract 14-12-0001-30426). Draft Report. Pacific OCS Region, Minerals Mgmt. Serv., Los Angeles, CA.
- Brueggeman, J.J., G.A. Green, K.C. Balcomb, C.E. Bowlby, R.A. Grotefendt, K.T. Briggs, M.L. Bonnell, R.G. Ford, D.H. Varoujean, D. Heinemann, and D.G. Chapman. 1990. Oregon-Washington marine mammal and seabird survey: information synthesis and hypothesis formulation. OCS Study MMS 89-0030. Rep. from Envirosphere Co., Bellevue, WA, and Ecological Consulting Inc., Portland, OR, for U.S. Minerals Manage. Serv., Pacific Region, Los Angeles, CA. 374 p.
- Buchanan, J.B., D.H. Johnson, E.L. Greda, G.A. Green, T.R. Wahl, and S.J. Jeffries. 2001. Wildlife of coastal and marine habitats. p. 389-422 *In: D.H. Johnson and T.A. O'Neil (eds.), Wildlife-habitat relationships in Oregon and Washington.* Oregon State University Press.
- Bui, S., F. Oppedal, Ø.J. Korsøen, D. Sonny, and T. Dempster. 2013. Group behavioural responses of Atlantic salmon (*Salmo salar* L.) to light, infrasound and sound stimuli. **PLoS ONE** 8(5):e63696. <http://dx.doi.org/doi:10.1371/journal.pone.0063696>.
- Byron, C.J. and B.J. Burke. 2014. Salmon ocean migration models suggest a variety of population-specific strategies. **Rev. Fish Biol. Fish.** 24(3):737-756.
- Caballero, S., H. Hamilton, C. Jaramillo, J. Capella, L. Flórez-González, C. Olavarria, H. Rosenbaum, F. Guhl, and C.S. Baker. 2001. Genetic characterisation of the Colombian Pacific Coast humpback whale population using RAPD and mitochondrial DNA sequences. **Mem. Queensl. Mus.** 47(2):459-464.
- Calambokidis, J. and J. Barlow. 2004. Abundance of blue and humpback whales in the eastern North Pacific estimated by capture-recapture and line-transect methods. **Mar. Mamm. Sci.** 20:63-85.
- Calambokidis, J., J.L. Laake, and A. Pérez. 2014. Updated analysis of abundance and population structure of seasonal gray whales in the Pacific Northwest, 1996-2012. Document submitted to the Range-Wide Workshop on Gray Whale Stock Structure, April 8-11, 2014 in La Jolla, CA. 75 p.
- Calambokidis, J., G.H. Steiger, J.C. Cabbage, K.C. Balcomb, C. Ewald, S. Kruse, R. Wells, and R. Sears. 1990. Sightings and movements of blue whales off central California 1986–88 from photo-identification of individuals. **Rep. Int. Whal. Comm. Spec. Iss.** 12:343-348.
- Calambokidis, J., G.H. Steiger, K. Rasmussen, J. Urbán R., K.C. Balcomb, P. Ladrón De Guevara, M. Salinas Z., J.K. Jacobsen, C.S. Baker, L.M. Herman, S. Cerchio, and J.D. Darling. 2000. Migratory destinations of humpback whales from the California, Oregon and Washington feeding ground. **Mar. Ecol. Prog. Ser.** 192:295-304.
- Calambokidis, J., G.H. Steiger, J.M. Straley, L.M. Herman, S. Cerchio, D.R. Salden, J. Urbán R., J.K. Jacobsen, O. von Ziegesar, K.C. Balcomb, C.M. Gabrielle, M.E. Dahlheim, S. Uchida, G. Ellis, Y. Miyamura, P.L. de Guevara, M. Yamaguchi, F. Sato, S.A. Mizroch, L. Schlender, K. Rasmussen, J. Barlow, and T.J. Quinn II. 2001. Movements and population structure of humpback whales in the North Pacific. **Mar. Mamm. Sci.** 17(4):769-794.

- Calambokidis, J., G. H. Steiger, D.K. Ellifrit, B.L. Troutman, and C.E. Bowlby. 2004. Distribution and abundance of humpback whales (*Megaptera novaeangliae*) and other marine mammals off the northern Washington coast. **Fish. Bull.** 102:563-580.
- Calambokidis, J., E.A. Falcone, T.J. Quinn, A.M. Burdin, P.J. Clapham, J.K.B. Ford, C.M. Gabriele, R. LeDuc, D. Mattila, L. Rojas-Bracho, J.M. Straley, B.L. Taylor, J. Urban R., D. Weller, B.H. Witteveen, M. Yamaguchi, A. Bendlin, D. Camacho, K. Flynn, A. Havron, J. Huggins, and N. Maloney. 2008. SPLASH: structure of populations, levels of abundance and status of humpback whales in the North Pacific. Rep. AB133F-03-RP-0078 for U.S. Dept. of Comm., Seattle, WA.
- Calambokidis, J., G.H. Steiger, C. Curtice, J. Harrison, M.C. Ferguson, E. Becker, M. DeAngelis, and S.M. Van Parijs. 2015. 4. Biologically important areas for selected cetaceans within U.S. waters – West Coast Region. **Aquat. Mamm.** 41(1):39-53.
- Campana, I., R. Crosti, D. Angeletti, L. Carosso, L. Davis, N. Di-Méglio, A. Moulins, M. Rosso, P. Tepsich, and A. Arcangeli. 2015. Cetacean response to summer maritime traffic in the western Mediterranean Sea. **Mar. Environ. Res.** 109:1-8.
- Carretta, J.V. and L. Enriquez. 2006. Marine mammal and sea turtle bycatch in the California/Oregon thresher shark and swordfish drift gillnet fishery in 2005. Admin. Rep. LJ-07-06. Nat. Mar. Fish. Serv., Southwest Fish. Sci. Center, La Jolla, CA. 9 p.
- Carretta, J.V. and L. Enriquez. 2010. Marine mammal and sea turtle bycatch in the California/Oregon thresher shark and swordfish drift gillnet fishery in 2009. Admin. Rep. LJ-10-03. Nat. Mar. Fish. Serv., Southwest Fish. Sci. Center, La Jolla, CA. 11 p.
- Carretta, J.V. and K.A. Forney. 1993. Report of the two aerial surveys for marine mammals in California coastal waters using a NOAA DeHavilland Twin Otter aircraft, 9 March–7 April 1991, 8 February–6 April 1992. NOAA Tech. Memo. NMFS-SWFSC-185. Nat. Mar. Fish. Serv., Southwest Fish. Sci. Center, La Jolla, CA. 77 p.
- Carretta, J.V., M.S. Lynn, and C.A. LeDuc. 1994. Right whale, *Eubalaena glacialis*, sighting off San Clemente Island, California. **Mar. Mamm. Sci.** 10(1):101-104.
- Carretta, J.V., E.M. Oleson, J. Baker, D.W. Weller, A.R. Lang, K.A. Forney, M.M. Muto, B. Hanson, A.J. Orr, H. Huber, M.S. Lowry, J. Barlow, J.E. Moore, D. Lynch, L. Carswell, and R.L. Brownwell, Jr. 2016a. U.S. Pacific marine mammal stock assessments: 2015. NOAA Tech. Memo. NOAA-TM-NMFS-SWFSC-561. Nat. Mar. Fish. Serv., Southwest Fish. Sci. Center, La Jolla, CA. 419 p.
- Carretta, J.V., M.M. Muto, S. Wilkin, J. Greenman, K. Wilkinson, M. DeAngelis, J. Viezbicke, and J. Jannot. 2016b. Sources of human-related injury and mortality for U.S. Pacific west coast marine mammal stock assessments, 2010-2014. NOAA-TM-NMFS-SWFSC-554. Nat. Mar. Fish. Serv., Southwest Fish. Sci. Center, La Jolla, CA. 102 p.
- Carretta, J.V., K.A. Forney, E.M. Oleson, D.W. Weller, A.R. Lang, J. Baker, M.M. Muto, B. Hanson, A.J. Orr, H. Huber, M.S. Lowry, J. Barlow, J.E. Moore, D. Lynch, L. Carswell, and R.L. Brownwell, Jr. 2017. U.S. Pacific marine mammal stock assessments: 2016. NOAA Tech. Memo. NOAA-TM-NMFS-SWFSC-577. Nat. Mar. Fish. Serv., Southwest Fish. Sci. Center, La Jolla, CA. 407 p.
- Carretta, J.V., K.A. Forney, E.M. Oleson, D.W. Weller, A.R. Lang, J. Baker, M.M. Muto, B. Hanson, A.J. Orr, H. Huber, M.S. Lowry, J. Barlow, J.E. Moore, D. Lynch, L. Carswell, and R.L. Brownwell, Jr. 2018. U.S. Pacific marine mammal stock assessments: 2017. NOAA Tech. Memo. NOAA-TM-NMFS-SWFSC-602. Nat. Mar. Fish. Serv., Southwest Fish. Sci. Center, La Jolla, CA. 155 p.
- Carroll, A.G., R. Przeslawski, A. Duncan, M. Gunning, and B. Bruce. 2017. A review of the potential impacts of marine seismic surveys on fish & invertebrates. **Mar. Poll. Bull.** 114:9-24.

- Castellote, M. and C. Llorens. 2016. Review of the effects of offshore seismic surveys in cetaceans: Are mass strandings a possibility? p. 133-143 *In*: A.N. Popper and A. Hawkins (eds.), The effects of noise on aquatic life II. Springer, New York, NY. 1292 p.
- Castellote, M., C.W. Clark, and M.O. Lammers. 2012. Acoustic and behavioural changes by fin whales (*Balaenoptera physalus*) in response to shipping and airgun noise. **Biol. Conserv.** 147(1):115-122.
- CBD (Convention on Biological Diversity). 2016a. Ecologically or Biologically Significant Areas: Northeast Pacific Ocean Seamounts. Accessed on 15 November 2018 at <https://chm.cbd.int/database/record?documentID=204132>.
- CBD. 2016b. Ecologically or Biologically Significant Areas: Juan de Fuca Ridge Hydrothermal Vents. Accessed on 15 November 2018 at <https://chm.cbd.int/database/record?documentID=204133>.
- CBD. 2016c. Ecologically or Biologically Significant Areas: North Pacific Transition Zone. Accessed on 15 November 2018 at <https://chm.cbd.int/database/record?documentID=204130>.
- Celi, M., F. Filiciotto, D. Parrinello, G. Buscaino, M.A. Damiano, A. Cuttitta, S. D'Angelo, S. Mazzola, and M. Vazzana. 2013. Physiological and agonistic behavioural response of *Procambarus clarkii* to an acoustic stimulus. **J. Exp. Biol.** 216(4):709-718.
- Cerchio, S., S. Strindberg, T. Collins, C. Bennett, and H. Rosenbaum. 2014. Seismic surveys negatively affect humpback whale singing activity off northern Angola. **PLoS ONE** 9(3):e86464. <http://dx.doi.org/doi:10.1371/journal.pone.0086464>.
- Cholewiak, D., A. Izzi, D. Palka, P. Corkeron, and S. Van Parijs. 2017. Beaked whales demonstrate a marked acoustic response to the use of shipboard echosounders. Abstract and presentation at the Society for Marine Mammalogy's 22nd Biennial Conference on the Biology of Marine Mammals, 22–27 October, Halifax, NS, Canada.
- Cholewiak, D., C.W. Clark, D. Ponirakis, A. Frankel, L.T. Hatch, D. Risch, J.E. Stanistreet, M. Thompson, E. Vu, S.M. Van Parijs. 2018. Communicating amidst the noise: modeling the aggregate influence of ambient and vessel noise on baleen whale communication space in a national marine sanctuary. **Endang. Species Res.** 36:59-75.
- Christensen-Dalsgaard, J., C. Brandt, K.L. Willis, C. Bech Christensen, D. Ketten, P. Edds-Walton, R.R. Fay, P.T. Madsen, and C.E. Carr. 2012. Specialization for underwater hearing by the tympanic middle ear of the turtle, *Trachemys scripta elegans*. **Proc. R. Soc. B** 279(1739):2816-2824.
- Clapham, P.J. 2009. Humpback whale. p. 582-595 *In*: W.F. Perrin, B. Würsig, and J.G.M. Thewissen (eds.), Encyclopedia of marine mammals, 2nd edit. Academic Press, San Diego, CA. 1316 p.
- Clapham, P.J. and D.K. Mattila. 1990. Humpback whale songs as indicators of migration routes. **Mar. Mamm. Sci.** 6(2):155-160.
- Clapham P.J. and J.G. Mead. 1999. *Megaptera novaeangliae*. **Mamm. Spec.** 604:1-9.
- Clark, C.W. and G.C. Gagnon. 2006. Considering the temporal and spatial scales of noise exposures from seismic surveys on baleen whales. Working Pap. SC/58/E9. Int. Whal. Comm., Cambridge, UK. 9 p.
- Clark, C.W., W.T. Ellison, B.L. Southall, L. Hatch, S.M. Van Parijs, A. Frankel, and D. Ponirakis. 2009. Acoustic masking in marine ecosystems: intuitions, analysis, and implication. **Mar. Ecol. Prog. Ser.** 395:201-222.
- COASST (Coastal Observation and Seabird Survey Team). 2016. A rare marine mammal washed in. Accessed in March 2017 at <http://blogs.uw.edu/coasst/tag/washington/>.
- COSEWIC. 2013. COSEWIC assessment and status report on the Short-tailed Albatross *Phoebastria albatrus* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. xii + 55 p.
- Costa, D.P., L. Schwarz, P. Robinson, R. Schick, P.A. Morris, R. Condit, D.E. Crocker, and A.M. Kilpatrick. 2016a. A bioenergetics approach to understanding the population consequences of disturbance: elephant

- seals as a model system. p. 161-169 *In*: A.N. Popper and A. Hawkins (eds.), The effects of noise on aquatic life II. Springer, New York, NY. 1292 p.
- Costa, D.P., L.A. Huckstadt, L.K. Schwarz, A.S. Friedlaender, B.R. Mate, A.N. Zerbini, A. Kennedy, and N.J. Gales. 2016b. Assessing the exposure of animals to acoustic disturbance: towards an understanding of the population consequences of disturbance. *Proceedings of Meetings on Acoustics 4ENAL 27(1):010027*. <http://dx.doi.org/doi:10.1121/2.0000298>.
- 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. 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. **J. Cetac. Res. Manage.** 7(3):177-187.
- Crowell, S.C. 2016. Measuring in-air and underwater hearing in seabirds. p. 1155-1160 *In*: A.N. Popper and A. Hawkins (eds.), The effects of noise on aquatic life II. Springer, New York, NY. 1292 p.
- Culloch, R.M., P. Anderwald, A. Brandecker, D. Haberlin, B. McGovern, R. Pinfield, F. Visser, M. Jessopp, and M. Cronin. 2016. Effect of construction-related activities and vessel traffic on marine mammals. **Mar. Ecol. Prog. Ser.** 549:231-242.
- Currie, J.J., S.H. Stack, and G.D. Kaufman. 2017. Modelling whale-vessel encounters: the role of speed in mitigating collisions with humpback whales (*Megaptera novaeangliae*). **J. Cetacean Res. Manage.** 17(1):57-63.
- Dahlheim, M. and M. Castellote. 2016. Changes in the acoustic behavior of gray whales *Eschrichtius robustus* in response to noise. **Endang. Species Res.** 31:227-242.
- Daly, E.A., J.A. Scheurer, R.D. Brodeur, L.A. Weitkamp, B.R. Beckman, and J.A. Miller. 2014. Juvenile steelhead distribution, migration, feeding, and growth in the Columbia River estuary, plume, and coastal waters. **Mar. Coast. Fish.** 6(1):62-80.
- Darling, J.D. and S. Cerchio. 1993. Movement of a humpback whale (*Megaptera novaeangliae*) between Japan and Hawaii. **Mar. Mamm. Sci.** 9:84-89.
- Davis, R.W., G.S. Fargion, N. May, T.D. Leming, M. Baumgartner, W.E. Evans, L.J. Hansen, and K. Mullin. 1998. Physical habitat of cetaceans along the continental slope in the north-central and western Gulf of Mexico. **Mar. Mamm. Sci.** 14(3):490-507.
- Day, R.D., R.D. McCauley, Q.P. Fitzgibbon, and J.M. Semmens. 2016a. Seismic air gun exposure during early-stage embryonic development does not negatively affect spiny lobster *Jasus edwardsii* larvae (Decapoda: Palinuridae). **Sci. Rep.** 6:22723.
- Day, R.D., R.D. McCauley, Q.P. Fitzgibbon, K. Hartmann and J.M. Semmens. 2016b. Assessing the impact of marine seismic surveys on southeast Australian scallop and lobster fisheries. Fisheries Research & Development Corporation (FRDC). FRDC Project No 2012/008. 144 p.
- Day, R.D., R.D. McCauley, Q.P. Fitzgibbon, K. Hartmann and J.M. Semmens. 2017. Exposure to seismic air gun signals causes physiological harm and alters behavior in the scallop *Pecten fumatus*. **PNAS** 114(40):E8537-E8546. <http://doi.org/10.1073/pnas.1700564114>.
- Deng, Z.D., B.L. Southall, T.J. Carlson, J. Xu, J.J. Martinez, M.A. Weiland, and J.M. Ingraham. 2014. 200-kHz commercial sonar systems generate lower frequency side lobes audible to some marine mammals. **PLoS ONE** 9(4):e95315. <http://dx.doi.org/doi:10.1371/journal.pone.0095315>.
- DeRuiter, S.L. and K.L. Doukara. 2012. Loggerhead turtles dive in response to airgun sound exposure. **Endang. Species Res.** 16(1):55-63.
- DFO (Fisheries and Oceans Canada). 2004. Potential impacts of seismic energy on snow crab. DFO Can. Sci. Advis. Sec. Habitat Status Rep. 2004/003.

- DFO. 2018a. Marine protected areas (MPAs) and their regulations. Fisheries and Oceans Canada, Government of Canada. Accessed on 15 November 2018 at <http://www.dfo-mpo.gc.ca/oceans/mpa-zpm/index-eng.html>.
- DFO. 2018b. Salmon facts - Pacific salmon. Fisheries and Oceans Canada, Government of Canada. Accessed on 21 November 2018 at <http://www.pac.dfo-mpo.gc.ca/fm-gp/species-especies/salmon-saumon/facts-infos-eng.html>.
- Di Iorio, L. and C.W. Clark. 2010. Exposure to seismic survey alters blue whale acoustic communication. **Biol. Lett.** 6(1):51-54.
- Dohl, T.P., K.S. Norris, R.C. Guess, J.D. Bryant, and M.W. Honig. 1980. Summary of marine mammal and seabird surveys of the Southern California Bight area, 1975–1978. Part II. Cetaceans of the Southern California Bight. Final Report to the Bureau of Land Management, NTIS Rep. No. PB81248189. 414 p.
- 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. Final Report to the Minerals Management Service, Contract No. 14-12-0001-29090. 284 p.
- Dolman, S.J., and M. Jasny. 2015. Evolution of marine noise pollution management. **Aquat. Mammal.** 41(4):357-374.
- Donovan, G.P. 1991. A review of IWC stock boundaries. **Rep. Int. Whal. Comm. Spec. Iss.** 13:39-63.
- Donovan, C.R., C.M. Harris, L. Milazzo, J. Harwood, L. Marshall, and R. Williams. 2017. A simulation approach to assessing environmental risk of sound exposure to marine mammals. **Ecol. Evol.** 7:2101-2111.
- Dorsey, E.M., S.J. Stern, A.R. Hoelzel, and J. Jacobsen. 1990. Minke whale (*Balaenoptera acutorostrata*) from the west coast of North America: individual recognition and small-scale site fidelity. **Rept. Int. Whal. Comm. Spec. Iss.** 12:357-368.
- Duffield, D.A., S.H. Ridgway, and L.H. Cornell. 1983. Hematology distinguishes coastal and offshore forms of dolphins (*Tursiops*). **Can. J. Zool.** 61(4):930-933.
- Dunlop, R.A. 2015. The effect of vessel noise on humpback whale, *Megaptera novaeangliae*, communication behaviour. **Animal Behav.** 111:13-21.
- Dunlop, R.A., M.J. Noad, R.D. McCauley, E. Kniest, D. Paton, and D.H. Cato. 2015. The behavioural response of humpback whales (*Megaptera novaeangliae*) to a 20 cubic inch air gun. **Aquatic Mamm.** 41(4):412-433.
- Dunlop, R.A., M.J. Noad, R.D. McCauley, E. Kniest, R. Slade, D. Paton, and D.H. Cato. 2016a. Response of humpback whales (*Megaptera novaeangliae*) to ramp-up of a small experimental air gun array. **Mar. Poll. Bull.** 103:72-83.
- Dunlop, R.A., M.J. Noad, and D.H. Cato. 2016b. A spatially explicit model of the movement of humpback whales relative to a source. Proceedings of Meetings on Acoustics 4ENAL 27(1):010026. <http://dx.doi.org/doi:10.1121/2.0000296>.
- Dunlop, R., M.J. Noad, R. McCauley, and D. Cato. 2016c. The behavioral response of humpback whales to seismic air gun noise. **J. Acoust. Soc. Am.** 140(4):3412.
- Dunlop, R.A., M.J. Noad, R.D. McCauley, L. Scott-Hayward, E. Kniest, R. Slade, D. Paton, and D.H. Cato. 2017a. Determining the behavioural dose–response relationship of marine mammals to air gun noise and source proximity. **J. Exp. Biol.** 220:2878-2886.
- Dunlop, R.A., M.J. Noad, R.D. McCauley, E. Kniest, R. Slade, D. Paton, and D.H. Cato. 2017b. The behavioural response of migrating humpback whales to a full seismic airgun array. **Proc. R. Soc. B** 284:20171901. <http://dx.doi.org/10.1098/rspb.2017/1901>.
- Dutton, P.H., C. Hitipeuw, M. Zein, S.R. Benson, G. Petro, J. Piti, V. Rei, L. Ambio, and J. Bakarbesy. 2007. Status and genetic structure of nesting populations of leatherback turtles (*Dermochelys coriacea*) in the western Pacific. **Chel. Conserv. Biol.** 6(1):47-53.

- Dyndo, M., D.M. Wisniewska, L. Rojano-Doñate, and P.T. Madsen. 2015. Harbour porpoises react to low levels of high frequency vessel noise. **Sci. Rep.** 5:11083. <http://dx.doi.org/doi:10.1038/srep11083>.
- eBird. 2018. eBird: an online database of bird distribution and abundance [web application]. eBird, Ithaca, NY. Accessed November 2018 at <http://www.ebird.org>.
- Eckert, K.L. 1995. Leatherback sea turtle, *Dermochelys coriacea*. p. 37-75 *In*: P.T. Plotkin (ed.), National Marine Fisheries Service and U.S. Fish and Wildlife Service status reviews of sea turtles listed under the Endangered Species Act of 1973. Nat. Mar. Fish. Service, Silver Spring, MD. 139 p.
- Edmonds, N.J., C.J. Firmin, D. Goldsmith, R.C. Faulkner, and D.T. Wood. 2016. A review of crustacean sensitivity to high amplitude underwater noise: data needs for effective risk assessment in relation to UK commercial species. **Mar. Poll. Bull.** 108 (1-2):5-11.
- Edwards, E.F., C. Hall, T.J. Moore, C. Sheredy, and J.V. Redfern. 2015. Global distribution of fin whales *Balaenoptera physalus* in the post-whaling era (1980–2012). **Mammal Review** 45(4):197-214.
- Ellison, W.T., B.L. Southall, C.W. Clark, and A.S. Frankel. 2012. A new context-based approach to assess marine mammal behavioral responses to anthropogenic sounds. **Conserv. Biol.** 26(1):21-28.
- Ellison, W.T., R. Racca, C.W. Clark, B. Streever, A.S. Frankel, E. Fleishman, R. Angliss, J. Berger, D. Ketten, M. Guerra, M. Leu, M. McKenna, T. Sformo, B. Southall, R. Suydam, and L. Thomas. 2016. Modeling the aggregated exposure and responses of bowhead whales *Balaena mysticetus* to multiple sources of anthropogenic underwater sound. **Endang. Species Res.** 30:95-108.
- 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. Int. Whal. Comm., Cambridge, UK. 8 p.
- Erbe, C. 2012. The effects of underwater noise on marine mammals. p. 17-22 *In*: A.N. Popper and A. Hawkins (eds.), The effects of noise on aquatic life. Springer, New York, NY. 695 p.
- Erbe, C., C. Reichmuth, K. Cunningham, K. Lucke, and R. Dooling. 2016. Communication masking in marine mammals: a review and research strategy. **Mar. Poll. Bull.** 103:15-38.
- ERDDAP. 2018a. GODAE, SFCOBS – Surface temperature operations, 1998-present. ERDDAP Version 1.82. NOAA (National Oceanic and Atmospheric Administration), NMFS (National Marine Fisheries Service), SWFSC (Southwest Fisheries Science Centre) and ERD (NOAA SWFSC Environmental Research Division). Accessed on 14 November 2018 at <https://coastwatch.pfeg.noaa.gov/erddap/tabledap/erdGodaeSfcobs.html>.
- ERDDAP. 2018b. Chlorophyll-a, Aqua MODIS, NPP, 0.0125°, West US, EXPERIMENTAL, 2002-present (monthly composite), Lon+/-180. ERDDAP Version 1.82. NOAA (National Oceanic and Atmospheric Administration), NMFS (National Marine Fisheries Service), SWFSC (Southwest Fisheries Science Centre) and ERD (NOAA SWFSC Environmental Research Division). Accessed on 14 November 2018 at https://coastwatch.pfeg.noaa.gov/erddap/griddap/erdMWchlamday_LonPM180.html.
- ERDDAP. 2018c. Chlorophyll-a, Aqua MODIS, NPP, 0.0125°, West US, EXPERIMENTAL, 2002-present (1 Day Composite), Lon+/-180. ERDDAP Version 1.82. NOAA (National Oceanic and Atmospheric Administration), NMFS (National Marine Fisheries Service), SWFSC (Southwest Fisheries Science Centre) and ERD (NOAA SWFSC Environmental Research Division). Accessed on 14 November 2018 at https://coastwatch.pfeg.noaa.gov/erddap/griddap/erdMWchla1day_LonPM180.html.
- Escorza-Treviño, S. 2009. North Pacific marine mammals. p. 781-788 *In*: W.F. Perrin, B. Würsig, and J.G.M. Thewissen (eds.), Encyclopedia of marine mammals, 2nd edit. Academic Press, San Diego, CA. 1316 p.
- Evans, W.E. 1994. Common dolphin, white-bellied porpoise *Delphinus delphis* Linnaeus, 1758. p. 191-224 *In*: S.H. Ridgway and R. Harrison (eds.), Handbook of marine mammals, Vol. 5: The first book of dolphins. Academic Press, San Diego, CA. 416 p.

- Farmer, N., K. Baker, D. Zeddies, M. Zykov, D. Noren, L. Garrison, E. Fougères, and A. Machernis. 2017. Population consequences of disturbance for endangered sperm whales (*Physeter macrocephalus*) exposed to seismic surveys in the Gulf of Mexico, USA. Abstract and presentation at the Society for Marine Mammalogy's 22nd Biennial Conference on the Biology of Marine Mammals, 22–27 October, Halifax, NS, Canada.
- Fay, R.R. and A.N. Popper. 2012. Fish hearing: new perspectives from two senior bioacousticians. **Brain Behav. Evol.** 79(4):215-217.
- Ferguson, M.C. and J. Barlow. 2001. Spatial distribution and density of cetaceans in the eastern tropical Pacific Ocean based on summer/fall research vessel surveys in 1986–96. Admin. Rep. LJ-01-04, Nat. Mar. Fish. Serv., Southwest Fish. Sci. Center, La Jolla, CA. 61 p.
- Ferguson, M.C. and J. Barlow. 2003. Addendum: Spatial distribution and density of cetaceans in the eastern tropical Pacific Ocean based on summer/fall research vessel surveys in 1986–96. Admin. Rep. LJ-01-04, Nat. Mar. Fish. Serv., Southwest Fish. Sci. Center, La Jolla, CA. 120 p.
- Ferrero, R.C., R.C. Hobbs, and G.R. VanBlaricom. 2002. Indications of habitat use patterns among small cetaceans in the central North Pacific based on fisheries observer data. **J. Cetac. Res. Manage.** 4:311-321.
- Fewtrell, J.L. and R.D. McCauley. 2012. Impact of air gun noise on the behaviour of marine fish and squid. **Mar. Poll. Bull.** 64(5):984-993.
- Finkbeiner, E.M., B.P. Wallace, J.E. Moore, R.L. Lewison, L.B. Crowder, and A.J. Read. 2011. Cumulative estimates of sea turtle bycatch and mortality in USA fisheries between 1990 and 2007. **Biol. Conserv.** 144:2719-2727.
- Finneran, J.J. 2012. Auditory effects of underwater noise in odontocetes. p. 197-202 *In*: A.N. Popper and A. Hawkins (eds.), *The effects of noise on aquatic life*. Springer, New York, NY. 695 p.
- Finneran, J.J. 2015. Noise-induced hearing loss in marine mammals: a review of temporary threshold shift studies from 1996 to 2015. **J. Acoust. Soc. Am.** 138(3):1702-1726.
- Finneran, J.J. 2016. Auditory weighting functions and TTS/PTS exposure functions for marine mammals exposed to underwater noise. Technical Report 3026. SSC Pacific, San Diego, CA.
- Finneran, J.J. and B.K. Branstetter. 2013. Effects of noise on sound perception in marine mammals. p. 273-308 *In*: H. Brumm (ed.), *Animal communication and noise*. Springer Berlin, Heidelberg, Germany. 453 p.
- Finneran, J.J. and C.E. Schlundt. 2010. Frequency-dependent and longitudinal changes in noise-induced hearing loss in a bottlenose dolphin (*Tursiops truncatus*) (L). **J. Acoust. Soc. Am.** 128(2):567-570.
- Finneran, J.J. and C.E. Schlundt. 2011. Noise-induced temporary threshold shift in marine mammals. **J. Acoust. Soc. Am.** 129(4):2432. [Supplemented by oral presentation at the ASA meeting, Seattle, WA, May 2011].
- Finneran, J.J. and C.E. Schlundt. 2013. Effects of fatiguing tone frequency on temporary threshold shift in bottlenose dolphins (*Tursiops truncatus*). **J. Acoust. Soc. Am.** 133(3):1819-1826.
- 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 whales (*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., 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.A. Carder, C.E. Schlundt, and R.L. Dear. 2010a. Growth and recovery of temporary threshold shift (TTS) at 3 kHz in bottlenose dolphins (*Tursiops truncatus*). **J. Acoust. Soc. Am.** 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. **J. Acoust. Soc. Am.** 127(5):3267-3272
- Finneran, J.J., C.E. Schlundt, B.K. Branstetter, J.S. Trickey, V. Bowman, and K. Jenkins. 2015. Effects of multiple impulses from a seismic air gun on bottlenose dolphin hearing and behavior. **J. Acoust. Soc. Am.** 137(4):1634-1646.
- Fiscus C. and K. Niggol. 1965. Observations of cetaceans off California, Oregon, and Washington. U.S. Fish and Wildlife Service, Special Science Report-Fisheries No. 498. 27 p.
- Fitzgibbon, Q.P., R.D. Day, R.D. McCauley, C.J. Simon, and J.M. Semmens. 2017. The impact of seismic air gun exposure on the haemolymph physiology and nutritional condition of spiny lobster, *Jasus edwardsii*. **Mar. Poll. Bull.** 125(1-2):146-156.
- Ford, J.K.B. 2009. Killer whale. p. 650-657 *In*: W.F. Perrin, B. Würsig, and J.G.M. Thewissen (eds.), *Encyclopedia of marine mammals*, 2nd edit. Academic Press, San Diego, CA. 1316 p.
- Forney, K.A. 1994. Recent information on the status of odontocetes in California waters. NOAA Tech. Memo. NMFS-SWFSC-202. Nat. Mar. Fish. Serv., Southwest Fish. Sci. Center, La Jolla, CA. 87 p.
- Forney, K.A. 2007. Preliminary estimates of cetacean abundance along the U.S. west coast and within four National Marine Sanctuaries during 2005. NOAA Tech. Memo. NOAA-TM-NMFS-SWFSC-406. Nat. Mar. Fish. Serv., Southwest Fish. Sci. Center, La Jolla, CA.
- Forney, K.A., and J. Barlow. 1998. Seasonal patterns in the abundance and distribution of California cetaceans, 1991–1992. **Mar. Mamm. Sci.** 14 (3):460-489.
- Forney, K.A., J. Barlow, and J.V. Carretta. 1995. The abundance of cetaceans in California waters. Part II: aerial surveys in winter and spring of 1991 and 1992. **Fish. Bull.** 93:15-26.
- Forney, K.A., B.L. Southall, E. Slooten, S. Dawson, A.J. Read, R.W. Baird, and R.L. Brownell, Jr. 2017. Nowhere to go: noise impact assessments for marine mammal populations with high site fidelity. **Endang. Species Res.** 32:391-413.
- Frair, W., R.G. Ackman, and N. Mrosovsky. 1972. Body temperature of *Dermochelys coriacea*: warm turtle from cold water. **Science** 177:791-793.
- French, R., H. Bilton, M. Osako, and A.C. Hartt. 1976. Distribution and origin of sockeye salmon (*Oncorhynchus nerka*) in offshore waters of the North Pacific Ocean. International North Pacific Fisheries Commission, Vancouver, 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. **Environ. Monit. Assess.** 134(1-3):75-91.
- Gailey, G., O. Sychenko, T. McDonald, R. Racca, A. Rutenko, and K. Bröker. 2016. Behavioural responses of western gray whales to a 4-D seismic survey off northeastern Sakhalin Island, Russia. **Endang. Species Res.** 30:53-71.
- Gailey, G., O. Sychenko, A. Rutenko, and R. Racca. 2017. Western gray whale behavioral response to extensive seismic surveys conducted near their feeding grounds. Abstract and presentation at the Society for Marine Mammalogy's 22nd Biennial Conference on the Biology of Marine Mammals, 22–27 October, Halifax, NS, Canada.
- Gambell, R. 1985a. Sei whale *Balaenoptera borealis* Lesson, 1828. p. 155-170 *In*: S.H. Ridgway and R. Harrison (eds.), *Handbook of marine mammals*, Vol. 3: The sirenians and baleen whales. Academic Press, London, UK. 362 p.

- Gambell, R. 1985b. Fin whale *Balaenoptera physalus* (Linnaeus, 1758). p. 171-192 In: S.H. Ridgway and R. Harrison (eds.), Handbook of marine mammals, Vol. 3: The sirenians and baleen whales. Academic Press, London, UK. 362 p.
- Gannier, A. 2000. Distribution of cetaceans off the Society Islands (French Polynesia) as obtained from dedicated surveys. **Aquat. Mamm.** 26(2):111-126.
- Gedamke, J. 2011. Ocean basin scale loss of whale communication space: potential impacts of a distant seismic survey. p. 105-106 In: Abstr. 19th Bienn. Conf. Biol. Mar. Mamm., 27 Nov.–2 Dec. 2011, Tampa, FL. 344 p.
- Gedamke, J., N. Gales, and S. Frydman. 2011. Assessing risk of baleen whale hearing loss from seismic surveys: the effects of uncertainty and individual variation. **J. Acoust. Soc. Am.** 129(1):496-506.
- Gentry, R.L. 1981. Northern fur seal—*Callorhinus ursinus*. p. 119-141 In: S.H. Ridgway and R.J. Harrison (eds.), Handbook of marine mammals, Vol. 1: The walrus, sea lions, and sea otter. Academic Press, London, UK. 235 p.
- Gentry, R.L. 2009. Northern fur seal, *Callorhinus ursinus*. p. 788-791 In: W.F. Perrin, B. Würsig, and J.G.M. Thewissen (eds.), Encyclopedia of marine mammals, 2nd edit. Academic Press, San Diego, CA. 1316 p.
- Gervaise, C., N. Roy, Y. Simard, B. Kinda, and N. Menard. 2012. Shipping noise in whale habitat: characteristics, sources, budget, and impact on belugas in Saguenay-St. Lawrence Marine Park hub. **J. Acoust. Soc. Am.** 132(1):76-89.
- Gilmore, R.M. 1956. Rare right whale visits California. **Pac. Discov.** 9:20-25.
- Gilmore, R.M. 1978. Right whale. In: D. Haley (ed.), Marine mammals of eastern North Pacific and arctic waters. Pacific Search Press, Seattle, WA.
- Gomez, C., J.W. Lawson, A.J. Wright, A.D. Buren, D. Tollit, and V. Lesage. 2016. A systematic review on the behavioural responses of wild marine mammals to noise: the disparity between science and policy. **Can. J. Zool.** 94(12):801-819.
- Gong, Z., A.D. Jain, D. Tran, D.H. Yi, F. Wu, A. Zorn, P. Ratilal, and N.C. Makris. 2014. Ecosystem scale acoustic sensing reveals humpback whale behavior synchronous with herring spawning processes and re-evaluation finds no effect of sonar on humpback song occurrence in the Gulf of Maine in fall 2006. **PLoS ONE** 9(10):e104733. <http://dx.doi.org/doi:10.1371/journal.pone.0104733>.
- 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.
- Gray, H. and K. Van Waerebeek. 2011. Postural instability and akinesia in a pantropical spotted dolphin, *Stenella attenuata*, in proximity to operating airguns of a geophysical seismic vessel. **J. Nature Conserv.** 19(6):363-367.
- Green, G.A., J.J. Brueggeman, R.A. Grotefendt, C.E. Bowlby, M.L. Bonnell, and K.C. Balcomb, III. 1992. Cetacean distribution and abundance off Oregon and Washington, 1989–1990. Chapter 1 In: J.J. Brueggeman (ed.), Oregon and Washington marine mammal and seabird surveys. Minerals Manage. Serv. Contract Rep. 14-12-0001-30426.
- Green, G.A., R.A. Grotefendt, M.A. Smultea, C.E. Bowlby, and R.A. Rowlett. 1993. Delphinid aerial surveys in Oregon and Washington offshore waters. Rep. from Ebasco Environmental, Bellevue, WA, for Nat. Mar.
- Greer, A.E., J.D. Lazell, Jr., and R.M. Wright. 1973. Anatomical evidence for counter-current heat exchanger in the leatherback turtle (*Dermochelys coriacea*). **Nature** 244:181.
- Gregg, E.J. and A.W. Trites. 2001. Predictions of critical habitat of five whale species in the waters of coastal British Columbia. **Can. J. Fish. Aquat. Sci.** 58(7):1265-1285.

- Gridley, T., S.H. Elwen, G. Rashley, A.B. Krakauer, and J. Heiler. 2016. Bottlenose dolphins change their whistling characteristics in relation to vessel presence, surface behavior and group composition. *Proceedings of Meetings on Acoustics* 4ENAL 27(1):010030. <http://dx.doi.org/doi:10.1121/2.0000312>.
- Guan, S., J.F. Vignola, J.A. Judge, D. Turo, and T.J. Ryan. 2015. Inter-pulse noise field during an arctic shallow-water seismic survey. **J. Acoust. Soc. Am.** 137(4):2212.
- Guerra, M., A.M. Thode, S.B. Blackwell, and M. Macrander. 2011. Quantifying seismic survey reverberation off the Alaskan North Slope. **J. Acoust. Soc. Am.** 130(5):3046-3058.
- Guerra, M., P.J. Dugan, D.W. Ponirakis, M. Popescu, Y. Shiu, and C.W. Clark. 2016. High-resolution analysis of seismic airgun impulses and their reverberant field as contributors to an acoustic environment. p. 371-379 *In: A.N. Popper and A. Hawkins (eds.), The effects of noise on aquatic life II.* Springer, New York, NY. 1292 p.
- Hain, J.H.W., W.A.M. Hyman, R.D. Kenney, and H.E. Winn. 1985. The role of cetaceans in the shelf-edge region of the U.S. **Mar. Fish. Rev.** 47(1):13-17.
- Hall, J. 1979. A survey of cetaceans of Prince William Sound and adjacent waters: their numbers and seasonal movements. Unpubl. Rep. to Alaska Outer Continental Shelf Environmental Assessment Programs. NOAA OSCEAP Juneau Project Office, Juneau, AK.
- Halliday, W.D., S.J. Insley, R.C. Hilliard, T. de Jong, and M.K. Pine. 2017. Potential impacts of shipping noise on marine mammals in the western Canadian Arctic. **Mar. Poll. Bull.** 123:73–82.
- Handegard, N.O., T.V. Tronstad, and J.M. Hovem. 2013. Evaluating the effect of seismic surveys on fish—The efficacy of different exposure metrics to explain disturbance. **Can. J. Fish. Aquat. Sci.** 70(9):1271-1277.
- Hansen, K.A., A. Maxwell, U. Siebert, O.N. Larsen, and M. Wahlberg. 2017. Great cormorants (*Phalacrocorax carbo*) can detect auditory cues while diving. **Sci. Nat.** 104:45.
- Hansen, L.J., K.D. Mullin, and C.L. Roden. 1994. Preliminary estimates of cetacean abundance in the northern Gulf of Mexico, and selected species in the U.S. Atlantic exclusive economic zone from vessel surveys. Miami Lab Contrib. No. MIA-93/94-58. Nat. Mar. Fish. Serv., Southeast Fish. Sci. Center, Miami, FL. 14 p.
- Harrington, J.J., J. McAllister, and J.M. Semmens. 2010. Assessing the short-term impact of seismic surveys on adult commercial scallops (*Pecten fumatus*) in Bass Strait. Tasmanian Aquaculture and Fisheries Institute, University of Tasmania.
- Harris, C.M., L. Thomas, E.A. Falcone, J. Hildebrand, D. Houser, P.H. Kvasdheim, F.-P.A. Lam, P.J.O. Miller, D.J. Moretti, A.J. Read, H. Slabbekoorn, B.L. Southall, P.L. Tyack, D. Wartzok, and V.M. Janik. 2017. Marine mammals and sonar: dose–response studies, the risk-disturbance hypothesis and the role of exposure context. **J. Appl. Ecol.** <http://dx.doi.org/doi:10.1111/1365-2566.12955>.
- Harwood, J., S. King, C. Booth, C. Donovan, R.S. Schick, L. Thomas, and L. New. 2016. Understanding the population consequences of acoustic disturbance for marine mammals. **Adv. Exp. Med. Biol.** 875:417-243.
- Hastie, G.D., C. Donovan, T. Götz, and V.M. Janik. 2014. Behavioral responses of grey seals (*Halichoerus grypus*) to high frequency sonar. **Mar. Poll. Bull.** 79(1-2):205-210.
- Hastings, M.C. and J. Miksis-Olds. 2012. Shipboard assessment of hearing sensitivity of tropical fishes immediately after exposure to seismic air gun emissions at Scott Reef. p. 239-243 *In: A.N. Popper and A. Hawkins (eds.), The effects of noise on aquatic life.* Springer, New York, NY. 695 p.
- Hatch, L.T., C.W. Clark, S.M. Van Parijs, A.S. Frankel, and D.W. Ponirakis. 2012. Quantifying loss of acoustic communication space for right whales in and around a U.S. National Marine Sanctuary. **Conserv. Biol.** 26(6):983-994.

- Hawkins, A.D. and A.N. Popper. 2017. A sound approach to assessing the impact of underwater noise on marine fishes and invertebrates. **ICES. J. Mar. Sci.** 74(3):635–651.
- Hawkins, A.D., A.E. Pembroke, and A.N. Popper. 2015. Information gaps in understanding the effects of noise on fishes and invertebrates. **Rev. Fish Biol. Fisher.** 25(1):39-64. <http://dx.doi.org/doi:10.1007/s11160-014-9369-3>.
- Hazen, E.L., D.M. Palacios, K.A. Forney, E.A. Howell, E. Becker, A.L. Hoover, L. Irvine, M. DeAngelis, S.J. Bograd, B.R. Mate, and H. Bailey. 2017. WhaleWatch: a dynamic management tool for predicting blue whale density in the California Current. **J. Appl. Ecol.** 14 p. <http://dx.doi.org/doi:10.1111/1365-2664.12820>.
- Heide-Jørgensen, M.P., R.G. Hansen, S. Fossette, N.J. Nielsen, M.V. Jensen, and P. Hegelund. 2013a. Monitoring abundance and hunting of narwhals in Melville Bay during seismic surveys. September 2013. Greenland Institute of Natural Resources. 56 p.
- Heide-Jørgensen, M.P., R.G. Hansen, K. Westdal, R.R. Reeves, and A. Mosbech. 2013b. Narwhals and seismic exploration: Is seismic noise increasing the risk of ice entrapments? **Biol. Conserv.** 158:50-54.
- Heiler, J., S.H. Elwen, H.J. Kriesell, and T. Gridley. 2016. Changes in bottlenose dolphin whistle parameters related to vessel presence, surface behaviour and group composition. **Animal Behav.** 117:167-177.
- Herman, L. M., C.S. Baker, P.H. Forestell, and R.C. Antinaja. 1980. Right whale, *Balaena glacialis*, sightings near Hawaii: a clue to the wintering grounds? **Mar. Ecol. Prog. Ser.** 2:271-275.
- Hermanssen, L., J. Tougaard, K. Beedholm, J. Nabe-Nielsen, and P.T. Madsen. 2014. High frequency components of ship noise in shallow water with a discussion of implications for harbor porpoises (*Phocoena phocoena*). **J. Acoust. Soc. Am.** 136(4):1640-1653.
- Hermanssen, L., K. Beedholm, J. Tougaard, and P.T. Madsen. 2015. Characteristics and propagation of airgun pulses in shallow water with implications for effects on small marine mammals. **PLoS ONE** 10(7):e0133436. <http://dx.doi.org/doi:10.1371/journal.pone.0133436>.
- Heyning, J.E. 1989. Cuvier's beaked whale *Ziphius cavirostris* G. Cuvier, 1823. p. 289-308 *In*: S.H. Ridgway and R. Harrison (eds.), Handbook of marine mammals, Vol. 4: River dolphins and the larger toothed whales. Academic Press, San Diego, CA. 444 p.
- Heyning, J.E. and M.E. Dahlheim. 1988. *Orcinus orca*. **Mammal. Spec.** 304:1-9.
- Heyning, J.E. and W.F. Perrin. 1994. Evidence for two species of common dolphins (Genus *Delphinus*) from the eastern North Pacific. **Contr. Nat. Hist. Mus. L.A. County**, No. 442.
- Heyward, A., J. Colquhoun, E. Cripps, D. McCorry, M. Stowar, B. Radford, K. Miller, I. Miller, and C. Battershill. 2018. No evidence of damage to the soft tissue or skeletal integrity of mesophotic corals exposed to a 3D marine seismic survey. **Mar. Poll. Bull.** 129(1):8-13.
- Hill, P.S. and J. Barlow. 1992. Report of a marine mammal survey of the California coast aboard the research vessel *McArthur* July 28–November 5, 1991. NOAA Tech. Memo. NMFS-SWFSC-169. Nat. Mar. Fish. Serv., Southwest Fish. Sci. Center, La Jolla, CA. 103 p.
- Hindell, M.A. 2009. Elephant seals. p. 990-992 *In*: W.F. Perrin, B. Würsig, and J.G.M. Thewissen (eds.), Encyclopedia of marine mammals, 2nd edit. Academic Press, New York, NY. 1316 p.
- Hitipeuw, C., P.H. Dutton, S. Benson, J. Thebu, and J. Bakarbesy. 2007. Population status and interesting movement of leatherback turtles, *Dermochelys coriacea*, nesting on the northwest coast of Papua, Indonesia. **Chel. Conserv. Biol.** 6(1):28-36.
- Hodder J., R.F. Brown, and C. Czesla. 1998. The northern elephant seal in Oregon: a pupping range extension and onshore occurrence. **Mar. Mamm. Sci.** 14:873-881.

- Hoelzel, A.R., C.W. Potter, and P.B. Best. 1998. Genetic differentiation between parapatric ‘nearshore’ and ‘offshore’ populations of the bottlenose dolphin. **Proc. Roy. Soc. Lond. B** 265:1177-1183.
- 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.
- Holst, M. 2017. Marine mammal and sea turtle sightings during a survey of the Endeavour Segment of the Juan de Fuca Ridge, British Columbia. **Can. Field-Nat.** 131(2):120-124.
- Holt, M.M., D.P. Noren, R.C. Dunkin, and T.M. Williams. 2015. Vocal performance affects metabolic rate in dolphins: implications for animals communicating in noisy environments. **J. Exp. Biol.** 218(11):1647-1654. <http://dx.doi.org/doi:10.1242/jeb.122424>.
- Horwood, J. 1987. The sei whale: population biology, ecology, and management. Croom Helm, Beckenham, Kent, UK. 375 p.
- Houghton, J., M.M. Holt, D.A. Giles, M.B. Hanson, C.K. Emmons, J.T. Hogan, T.A. Branch, and G.R. VanBlaricom. 2015. The relationship between vessel traffic and noise levels received by killer whales (*Orcinus orca*). **PLoS ONE** 10(12): e0140119. <http://dx.doi.org/doi:10.1371/journal.pone.0140119>.
- Houser, D.S., C.D. Champagne, D.E. Crocker, N.M. Kellar, J. Cockrem, T. Romano, R.K. Booth, and S.K. Wasser. 2016. Natural variation in stress hormones, comparisons across matrices, and impacts resulting from induced stress in the bottlenose dolphin. p. 467-471 *In*: A.N. Popper and A. Hawkins (eds.), The effects of noise on aquatic life II. Springer, New York, NY. 1292 p.
- Houser, D.S., W. Yost, R. Burkhard, J.J. Finneran, C. Reichmuth, and J. Mulsow. 2017. A review of the history, development and application of auditory weighting functions in humans and marine mammals. **J. Acoust. Soc. Am.** 141(1371). <http://dx.doi.org/doi:10.1121/1.4976086>.
- Hovem, J.M., T.V. Tronstad, H.E. Karlsen, and S. Løkkeborg. 2012. Modeling propagation of seismic airgun sounds and the effects on fish behaviour. **IEEE J. Ocean. Eng.** 37(4):576-588.
- Huber H.R. 1991. Changes in the distribution of California sea lions north of the breeding rookeries during the 1982–83 El Niño. p. 129-137 *In*: F. Trillmich and K.A. Ono (eds.), Pinnipeds and El Niño/responses to environmental stress. Springer-Verlag, Berlin. 293 p.
- Huber, H.R., A.C. Rovetta, L.A. Fry, and S. Johnston. 1991. Age-specific natality of northern elephant seals at the Farallon Islands, California. **J. Mamm.** 72(3):525-534.
- Irvine, L.M., B.R. Mate, M.H. Winsor, D.M. Palacios, S.J. Bograd, D.P. Costa, and H. Bailey. 2014. Spatial and temporal occurrence of blue whales off the US West Coast, with implications for management. **PLoS One** 9(7):e102959.
- IUCN (The World Conservation Union). 2018. The IUCN Red List of Threatened Species. Version 2018-2. Accessed in November 2018 at <http://www.iucnredlist.org/>.
- IWC (International Whaling Commission). 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.
- Jannot, J., Heery, E., Bellman, M.A., and J. Majewski. 2011. Estimated bycatch of marine mammals, seabirds, and sea turtles in the U.S. west coast commercial groundfish fishery, 2002–2009. West coast groundfish observer program. Nat. Mar. Fish. Serv., Northwest Fish. Sci. Center, Seattle, WA. 104 p.
- Jaquet, N. and H. Whitehead. 1996. Scale-dependent correlation of sperm whale distribution with environmental features and productivity in the South Pacific. **Mar. Ecol. Prog. Ser.** 135(1-3):1-9.
- Jefferson, T.A., M.A. Webber, and R.L. Pitman. 2015. Marine mammals of the world: a comprehensive guide to their identification, 2nd edit. Academic Press, London, UK. 608 p.

- Jefferson, T.A., C.R. Weir, R.C. Anderson, L.T. Ballance, R.D. Kenney, and J.J. Kiszka. 2014. Global distribution of Risso's dolphin *Grampus griseus*: a review and critical evaluation. **Mamm. Rev.** 44(1):56-68.
- Jensen, F.H., L. Bejder, M. Wahlberg, N. Aguilar Soto, M. Johnson, and P.T. Madsen. 2009. Vessel noise effects on delphinid communication. **Mar. Ecol. Prog. Ser.** 395:161-175.
- Johansen, S., O.N. Larsen, J. Christensen-Dalsgaard, L. Seidelin, T. Huulvej, K. Jensen, S.-G. Linneryrd, M. Boström, and M. Wahlberg. 2016. In-air and underwater hearing in the great cormorant (*Phalacrocorax carbo sinensis*). p. 505-512 In: A.N. Popper and A. Hawkins (eds.), The effects of noise on aquatic life II. Springer, New York, NY. 1292 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. **Environ. Monit. Assess.** 134(1-3):1-19.
- Jones, N. 2016. A growing call for international marine reserves. YaleEnvironment360, Yale School of Forestry & Environmental Studies. Accessed on 15 November 2018 at https://e360.yale.edu/features/high_stakes_on_the_high_seas_international_marine_reserves.
- Jones, E.L., G.D. Hastie, S. Smout, J. Onoufriou, N.D. Merchant, K.L. Brookes, and D. Thompson. 2017. Seals and shipping: quantifying population risk and individual exposure to vessel noise. **J. Appl. Ecol.** dx.doi.org/doi:10.1111/1365-2664.12911.
- Kajimura, H. 1984. Opportunistic feeding of the northern fur seal, *Callorhinus ursinus*, in the eastern North Pacific Ocean and eastern Bering Sea. NOAA Tech. Rep. NMFS-SSRF-779. 49 p.
- Kamezaki, N., K. Oki, K. Mizuno, T. Toji, and O. Doi. 2002. First nesting record of the leatherback turtle, *Dermodochelys coriacea*, in Japan. **Curr. Herpetol.** 21(2):95-97.
- Kastak, D. and C. Reichmuth. 2007. Onset, growth, and recovery of in-air temporary threshold shift in a California sea lion (*Zalophus californianus*). **J. Acoust. Soc. Am.** 122(5):2916-2924.
- 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. 2005. Underwater temporary threshold shift in pinnipeds: effects of noise level and duration. **J. Acoust. Soc. Am.** 118(5):3154-3163.
- Kastak, D., J. Mulsow, A. Ghoul, and C. Reichmuth. 2008. Noise-induced permanent threshold shift in a harbor seal. **J. Acoust. Soc. Am.** 123(5):2986.
- Kastelein, R., R. Gransier, L. Hoek, and J. Olthuis. 2012a. Temporary threshold shifts and recovery in a harbor porpoise (*Phocoena phocoena*) after octave-band noise at 4 kHz. **J. Acoust. Soc. Am.** 132(5):3525-3537.
- Kastelein, R.A., R. Gransier, L. Hoek, A. Macleod, and J.M. Terhune. 2012b. Hearing threshold shifts and recovery in harbor seals (*Phoca vitulina*) after octave-band noise exposure at 4 kHz. **J. Acoust. Soc. Am.** 132(4):2745-2761.
- Kastelein, R.A., R. Gransier, L. Hoek, and C.A.F. de Jong. 2012c. The hearing threshold of a harbor porpoise (*Phocoena phocoena*) for impulsive sounds (L). **J. Acoust. Soc. Am.** 132(2):607-610.
- Kastelein, R.A., N. Steen, R. Gransier, and C.A.F. de Jong. 2013a. Brief behavioral response threshold level of a harbor porpoise (*Phocoena phocoena*) to an impulsive sound. **Aquat. Mamm.** 39(4):315-323.
- Kastelein, R.A., R. Gransier, and L. Hoek, and M. Rambags. 2013b. Hearing frequency thresholds of a harbour porpoise (*Phocoena phocoena*) temporarily affected by a continuous 1.5-kHz tone. **J. Acoust. Soc. Am.** 134(3):2286-2292.
- Kastelein, R., R. Gransier, and L. Hoek. 2013c. Comparative temporary threshold shifts in a harbour porpoise and harbour seal, and severe shift in a seal. **J. Acoust. Soc. Am.** 134(1):13-16.

- Kastelein, R.A., L. Hoek, R. Gransier, M. Rambags, and N. Clayes. 2014. Effect of level, duration, and inter-pulse interval of 1–2 kHz sonar signal exposures on harbor porpoise hearing. **J. Acoust. Soc. Am.** 136:412-422.
- Kastelein, R.A., R. Gransier, J. Schop, and L. Hoek. 2015a. Effects of exposure to intermittent and continuous 6-7 kHz sonar sweeps on harbor porpoise (*Phocoena phocoena*) hearing. **J. Acoust. Soc. Am.** 137(4):1623-1633.
- Kastelein, R.A., R. Gransier, M.A.T. Marijt, and L. Hoek. 2015b. Hearing frequency thresholds of harbor porpoises (*Phocoena phocoena*) temporarily affected by played back offshore pile driving sounds. **J. Acoust. Soc. Am.** 137(2):556-564.
- Kastelein, R.A., R. Gransier, and L. Hoek. 2016a. Cumulative effects of exposure to continuous and intermittent sounds on temporary hearing threshold shifts induced in a harbor porpoise (*Phocoena phocoena*). p. 523-528 *In: A.N. Popper and A. Hawkins (eds.), The effects of noise on aquatic life II.* Springer, New York, NY. 1292 p.
- Kastelein, R.A., L. Helder-Hoek, J. Covi, and R. Gransier. 2016b. Pile driving playback sounds and temporary threshold shift in harbor porpoises (*Phocoena phocoena*): effect of exposure duration. **J. Acoust. Soc. Am.** 139(5):2842-2851.
- Kastelein, R.A., L. Helder-Hoek, S. Van de Voorde, A.M. von Benda-Beckmann, F.P.A. Lam, E. Jansen, C.A.F. de Jong, and M.A. Ainslie. 2017. Temporary hearing threshold shift in a harbor porpoise (*Phocoena phocoena*) after exposure to multiple airgun sounds. **J. Acoust. Soc. Am.** 142(4):2430-2442.
- 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.
- Kasuya, T. 2009. Giant beaked whales. p. 498-500 *In: W.F. Perrin, B. Würsig, and J.G.M. Thewissen (eds.), Encyclopedia of marine mammals, 2nd edit.* Academic Press, San Diego, California. 1316 p.
- Kasuya, T. and T. Miyashita. 1988. Distribution of sperm whale stocks in the North Pacific. **Sci. Rep. Whales Res. Inst.** 39:31-75.
- Keating, J.L., J.N. Oswald, S. Rankin, and J. Barlow. 2015. Whistle classification in the California Current: a complete whistle classifier for a large geographic region with high species diversity. NOAA Tech. Memo. NMFS NOAA-TM-NMFS-SWFSC-552. U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, and Southwest Fisheries Science Center. 12 p. + appendix.
- Keating, J.L., J. Barlow, E.T. Griffiths, and J.E. Moore. 2018. Passive Acoustics Survey of Cetacean Abundance Levels (PASCAL-2016) final report. U.S. Dept. of the Interior, Bureau of Ocean Energy Management, Honolulu, HI. OCS Study BOEM 2018-025. 22 p.
- Kenney, R.D. 2009. Right whales *Eubalaena glacialis*, *E. japonica*, and *E. australis*. p. 962-972 *In: W.F. Perrin, B. Würsig, and J.G.M. Thewissen (eds.), Encyclopedia of marine mammals, 2nd ed.* Academic Press, San Diego, CA. 1316 p.
- Kenney, R.D. and H.E. Winn. 1987. Cetacean biomass densities near submarine canyons compared to adjacent shelf/slope areas. **Continent. Shelf Res.** 7:107-114.
- Ketten, D.R. 2012. Marine mammal auditory system noise impacts: evidence and incidence. p. 207-212 *In: A.N. Popper and A. Hawkins (eds.), The effects of noise on aquatic life.* Springer, New York, NY. 695 p.
- 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.
- King, S.L., R.S. Schick, C. Donovan, C.G. Booth, M. Burgman, L. Thomas, and J. Harwood. 2015. An interim framework for assessing the population consequences of disturbance. **Meth. Ecol. Evol.** 6(1):1150-1158.

- Klinck, H., S.L. Nieuwkerk, D.K. Mellinger, K. Klinck, H. Matsumoto, and R.P. Dziak. 2012. Seasonal presence of cetaceans and ambient noise levels in polar waters of the North Atlantic. **J. Acoust. Soc. Am.** 132(3):EL176-EL181.
- Kok, A.C.M., J.P. Engelberts, R.A. Kastelein, L. Helder-Hoek, S. Van de Voorde, F. Visser, H. Slabbekoorn. 2017. Spatial avoidance to experimental increase of intermittent and continuous sound in two captive harbour porpoises. **Env. Poll.** 233:1024-1036.
- Krieger, K.J. and B.L. Wing. 1984. Hydroacoustic surveys and identification of humpback whale forage in Glacier Bay, Stephens Passage, and Frederick Sound, southeastern Alaska, summer 1983. NOAA Tech. Memo. NMFS F/NWC-66. U.S. Natl. Mar. Fish. Serv., Auke Bay, AK. 60 p. NTIS PB85-183887.
- Krieger, K.J. and B.L. Wing. 1986. Hydroacoustic monitoring of prey to determine humpback whale movements. NOAA Tech. Memo. NMFS F/NWC-98. U.S. Natl. Mar. Fish. Serv., Auke Bay, AK. 63 p. NTIS PB86-204054.
- Kruse, S., D.K. Caldwell, and M.C. Caldwell. 1999. Risso's dolphin *Grampus griseus* (G. Cuvier, 1812). p. 183-212 *In*: S.H. Ridgway and R. Harrison (eds.), Handbook of marine mammals, Vol. 6: The second book of dolphins and the porpoises. Academic Press, San Diego, CA. 486 p.
- Kujawa, S.G. and M.C. Liberman. 2009. Adding insult to injury: cochlear nerve degeneration after "temporary" noise-induced hearing loss. **J. Neurosci.** 29(45):14077-14085.
- Kunc, H.P., K.E. McLaughlin, and R. Schmidt. 2016. Aquatic noise pollution: implications for individuals, populations, and ecosystems. **Proc. R. Soc. B** 283:20160839. <http://dx.doi.org/doi:10.1098/rspb.2016.0839>.
- Lalas, C. and H. McConnell. 2015. Effects of seismic surveys on New Zealand fur seals during daylight hours: do fur seals respond to obstacles rather than airgun noise? **Mar. Mamm. Sci.** <http://dx.doi.org/doi:10.1111/mms.12293>.
- Lavender, A.L., S.M. Bartol, and I.K. Bartol. 2014. Ontogenetic investigation of underwater hearing capabilities in loggerhead sea turtles (*Caretta caretta*) using a dual testing approach. **J. Exp. Biol.** 217(14):2580-2589.
- Laws, R. 2012. Cetacean hearing-damage zones around a seismic source. p. 473-476 *In*: A.N. Popper and A. Hawkins (eds.), The effects of noise on aquatic life. Springer, New York, NY. 695 p.
- Le Boeuf, B., D.P. Costa, A.C. Huntley, G.L. Kooyman, and R.W. Davis. 1986. Pattern and depth of dives in northern elephant seals. **J. Zool. Ser. A** 208:1-7.
- Le Boeuf, B.J., D. Crocker, S. Blackwell, and P. Morris. 1993. Sex differences in diving and foraging behavior of northern elephant seals. *In*: I. Boyd (ed.), Marine mammals: advances in behavioral and population biology. Oxford Univ. Press, London, UK.
- Le Boeuf, B.J., D.E. Crocker, D.P. Costa, S.B. Blackwell, P.M. Webb, and D.S. Houser. 2000. Foraging ecology of northern elephant seals. **Ecol. Monographs** 70(3):353-382.
- Le Prell, C.G. 2012. Noise-induced hearing loss: from animal models to human trials. p. 191-195 *In*: A.N. Popper and A. Hawkins (eds.), The effects of noise on aquatic life. Springer, New York, NY. 695 p.
- Lea, M.A., D. Johnson, R. Ream, J. Sterling, S. Melin, and T. Gelatt. 2009. Extreme weather events influence dispersal of naïve northern fur seals. **Biol. Lett.** 5:252-257.
- 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. National Oceanic and Atmospheric Administration Tech. Rep. Nat. Mar. Fish. Serv. Circ. 444. 245 p.
- Leatherwood, S., B.S. Stewart, and P.A. Folkens. 1987. Cetaceans of the Channel Islands National Marine Sanctuary. National Oceanic and Atmospheric Administration, Channel Islands National Marine Sanctuary, and Nat. Mar. Fish. Serv., Santa Barbara and La Jolla, CA. 69 p.

- Leite, L., D. Campbell, L. Versiani, J. Anchieta, C.C. Nunes, and T. Thiele. 2016. First report of a dead giant squid (*Architeuthis dux*) from an operating seismic vessel. **Mar. Biodivers. Rec.** 9:26.
- Lenhardt, M. 2002. Sea turtle auditory behavior. **J. Acoust. Soc. Amer.** 112(5, Pt. 2):2314 (Abstr.).
- Lesage, V., A. Omrane, T. Doniol-Valcroze, and A. Mosnier. 2017. Increased proximity of vessels reduces feeding opportunities of blue whales in St. Lawrence Estuary, Canada. **Endang. Species Res.** 32:351–361.
- Lewison, R.L., L.B. Crowder, B.P. Wallace, J.E. Moore, T. Cox, R. Zydels, S. McDonald, A. DiMatteo, D.C. Dunn, C.Y. Kot, and R. Bjorkland. 2014. Global patterns of marine mammal, seabird, and sea turtle bycatch reveal taxa-specific and cumulative megafauna hotspots. **PNAS** 111(14):5271-5276.
- LGL (LGL Limited). 2012. Environmental assessment of marine geophysical surveys by the R/V *Marcus G. Langseth* in the Northeastern Pacific Ocean, June–July 2012. LGL Report TA8118-1 prepared by LGL Limited, King City, ON, for Lamont-Doherty Earth Observatory, Palisades, NY, and National Science Foundation, Arlington, VA. 215 p.
- Lieberman, M.C., M.J. Epstein, S.S. Cleveland, H. Wang, and S.F. Maison. 2016. Toward a differential diagnosis of hidden hearing loss in humans. **PLoS ONE** 11(9):e0162726. <https://doi.org/10.1371/journal.pone.0162726>.
- Light, J.T., C.K. Harris, and R.L. Burgner. 1989. Ocean distribution and migration of steelhead (*Oncorhynchus mykiss*, formerly *Salmo gairdneri*). Document submitted to the International North Pacific Fisheries Commission. Fisheries Research Institute, University of Washington, Seattle. 50 p. FRI-UW-8912. Accessed on 21 November 2018 at <https://digital.lib.washington.edu/researchworks/bitstream/handle/1773/4115/8913.pdf>.
- Løkkeborg, S., E. Ona, A. Vold, and A. Salthaug. 2012. Sounds from seismic air guns: gear- and species-specific effects on catch rates and fish distribution. **Can. J. Fish. Aquat. Sci.** 69(8):1278-1291.
- 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.
- Luis, A.R., M.N. Couchinho, and M.E. Dos Santos. 2014. Changes in the acoustic behavior of resident bottlenose dolphins near operating vessels. **Mar. Mamm. Sci.** 30(4):1417-1426.
- Lurton, X. 2016. Modelling of the sound field radiated by multibeam echosounders for acoustical impact assessment. **Appl. Acoust.** 101:201-216.
- Lusseau, D. and L. Bejder. 2007. The long-term consequences of short-term responses to disturbance experience from whalewatching impact assessment. **Int. J. Comp. Psych.** 20(2-3):228-236.
- Lyamin, O.I., S.M. Korneva, V.V. Rozhnov, and L.M. Mukhametov. 2016. Cardiorespiratory responses to acoustic noise in belugas. p. 665-672 *In*: A.N. Popper and A. Hawkins (eds.), *The effects of noise on aquatic life II*. Springer, New York, NY. 1292 p.
- MacGillivray, A.O., R. Racca, and Z. Li. 2014. Marine mammal audibility of selected shallow-water survey sources. **J. Acoust. Soc. Am.** 135(1):EL35-EL40.
- MacLeod, C.D., N. Hauser, and H. Peckham. 2004. Diversity, relative density and structure of the cetacean community in summer months east of Great Abaco, Bahamas. **J. Mar. Biol. Assoc. U.K.** 84:469-474.
- MacLeod, C.D., W.F. Perrin, R. Pitman, J. Barlow, L. Ballance, A. D'Amico, T. Gerrodette, G. Joyce, K.D. Mullin, D.L. Palka, and G. T. Warring. 2006. Known and inferred distributions of beaked whale species (Cetacea: Ziphiidae). **J. Cetac. Res. Manage.** 7(3):271-286.
- 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. Engelhardt, and R.J. Paterson (eds.), *Proc. Worksh. Effects Explos. Mar.*

- Envir., Jan. 1985, Halifax, N.S. Tech. Rep. 5. Can. Oil & Gas Lands Admin., Environ. Prot. Br., Ottawa, ON. 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 U.S. Minerals Manage. Serv., 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.
- Mangels, K.F. and T. Gerrodette. 1994. Report of cetacean sightings during a marine mammal survey in the eastern Pacific Ocean and the Gulf of California aboard the NOAA ships *McArthur* and *David Starr Jordan*, July 28–November 6, 1993. NOAA Tech. Memo. NOAA-TM-NMFS-SWFSC-211. Nat. Mar. Fish. Serv., Southwest Fish. Sci. Center, La Jolla, CA.
- Mantua, N.J. 1999. The Pacific decadal oscillation: a brief overview for non-specialists, to appear in the Encyclopedia of Environmental Change. Joint Institute for the Study of the Atmosphere and Oceans University of Washington, Seattle, Washington, USA. <http://jisao.washington.edu/pdo/>.
- Mantua, N.J., S.R. Hare, Y. Zhang, J.M. Wallace, and R.C. Francis. 1997. A Pacific decadal climate oscillation with impacts on salmon. **Bull. Am. Meteor. Soc.** 78:1069-1079.
- Maravilla-Chavez, M.O. and M.S Lowry. 1999. Incipient breeding colony of Guadalupe fur seals at Isla Benito del Este, Baja California, Mexico. **Mar. Mamm. Sci.** 15:239-241.
- MarineTraffic. 2018. Life Ships Map–AIS–Vessel Traffic and Positions. MarineTraffic.com. Accessed on 19 November 2018 at <http://www.marinetraffic.com>.
- Marquez, M.R. 1990. Sea turtles of the world. An annotated and illustrated catalogue of sea turtle species known to date. FAO Species Catalogue, FAO Fisheries Synopsis No. 125, Volume 11. 81 p.
- Martin, K.J., S.C. Alessi, J.C. Gaspard, A.D. Tucker, G.B. Bauer and D.A. Mann. 2012. Underwater hearing in the loggerhead turtle (*Caretta caretta*): a comparison of behavioral and auditory evoked potential audiograms. **J. Exp. Biol.** 215(17):3001-3009.
- Martins, D.T.L., M.R. Rossi-Santos, and F.J. De Lima Silva. 2016. Effects of anthropogenic noise on the acoustic behaviour of *Sotalia guianensis* (Van Bénédén, 1864) in Pipa, North-eastern Brazil. **J. Mar. Biol. Assoc. U.K.** 2016:1-8. <http://dx.doi.org/doi:10.1017/S0025315416001338>.
- Mate, B.R., B.A. Lagerquist, and J. Calambokidis. 1999. Movements of North Pacific blue whales during the feeding season off southern California and their southern fall migration. **Mar. Mamm. Sci.** 15(4):1246-1257.
- Matos, F. 2015. Distribution of cetaceans in Vestfjorden, Norway, and possible impacts of seismic surveys. M.Sc. Thesis, University of Nordland, Norway. 45 p.
- Matthews, L. 2017. Harbor seal (*Phoca vitulina*) reproductive advertisement behavior and the effects of vessel noise. Ph.D. Thesis, Syracuse University. 139 p.
- McAlpine, D.F. 2009. Pygmy and dwarf sperm whales. p. 936-938 *In*: W.F. Perrin, B. Würsig, and J.G.M. Thewissen (eds.), Encyclopedia of marine mammals, 2nd edit. Academic Press, San Diego, CA. 1316 p.
- 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 (Austral. Petrol. Product. Explor. Assoc.) 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. 2000. 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. Assoc., Sydney, NSW. 188 p.
- MCI (Marine Conservation Institute). 2018. High seas protections. Atlas of Marine Protection, Marine Conservation Institute. Accessed on 15 November 2018 at https://e360.yale.edu/features/high_stakes_on_the_high_seas_international_marine_reserves.
- 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.
- McDonald, T.L., W.J. Richardson, K.H. Kim, and S.B. Blackwell. 2010. Distribution of calling bowhead whales exposed to underwater sounds from Northstar and distant seismic surveys, 2009. p. 6-1 to 6-38 *In*: W.J. Richardson (ed.), Monitoring of industrial sounds, seals, and bowhead whales near BP's Northstar oil development, Alaskan Beaufort Sea: Comprehensive report for 2005–2009. LGL Rep. P1133-6. Rep. by LGL Alaska Res. Assoc. Inc., Anchorage, AK, Greeneridge Sciences Inc., Santa Barbara, CA, WEST Inc., Cheyenne, WY, and Applied Sociocult. Res., Anchorage, AK, for BP Explor. (Alaska) Inc., Anchorage, AK. 265 p.
- McDonald, T.L., W.J. Richardson, K.H. Kim, S.B. Blackwell, and B. Streever. 2011. Distribution of calling bowhead whales exposed to multiple anthropogenic sound sources and comments on analytical methods. p. 199 *In*: Abstr. 19th Bienn. Conf. Biol. Mar. Mamm., 27 Nov.–2 Dec. 2011, Tampa, FL. 344 p.
- McGeady, R., B.J. McMahon, and S. Berrow. 2016. The effects of surveying and environmental variables on deep diving odontocete stranding rates along Ireland's coast. Proceedings of Meetings on Acoustics 4ENAL 27(1):040006. <http://dx.doi.org/doi:10.1121/2.0000281>.
- Mead, J.G. 1981. First records of *Mesoplodon hectori* (Ziphiidae) from the northern hemisphere and a description of the adult male. **J. Mammal.** 62:430-432.
- Mead, J.G. 1989. Beaked whales of the genus *Mesoplodon*. p. 349-430 *In*: S.H. Ridgway and R.J. Harrison (eds.), Handbook of marine mammals, Vol. 4: River dolphins and the larger toothed whales. Academic Press, San Diego, CA. 444 p.
- Mead, J.G., W.A. Walker, and W.J. Jouck. 1982. Biological observations on *Mesoplodon carlhubbsi* (Cetacea: Ziphiidae). **Smithson. Contrib. Zool.** 344.
- 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. Assess.** 134(1-3):107-136.
- Melcón, M.L., A.J. Cummins, S.M. Kerosky, L.K. Roche, S.M. Wiggins, and J.A. Hildebrand. 2012. Blue whales respond to anthropogenic noise. **PLoS ONE** 7(2):e32681. <http://dx.doi.org/doi:10.1371/journal.pone.0032681>.
- Menza, C., J. Leirness, T. White, A. Winship, B. Kinlan, L. Kracker, J.E. Zamon, L. Balance, E. Becker, K.A. Forney, J. Barlow, J. Adams, D. Pereksta, S. Pearson, J. Pierce, S. Jeffries, J. Calambokidis, A. Douglas, B. Hanson, S.R. Benson, and L. Antrim. 2016. Predictive mapping of seabirds, pinnipeds and cetaceans off the Pacific coast of Washington. NOAA Tech. Memo. NOS NCCOS 210. Silver Spring, MD. 96 p. <http://dx.doi.org/doi:10.7289/V5NV9G7Z>.
- Miller, I. and E. Cripps. 2013. Three dimensional marine seismic survey has no measurable effect on species richness or abundance of a coral reef associated fish community. **Mar. Poll. Bull.** 77(1-2):63-70.
- 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 U.S. 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. 631 p.
- 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.
- Minobe, S. 1997. A 50–70 year climatic oscillation over the North Pacific and North America. **Geophys. Res. Lett.** **24**:683-686.
- Mitchell, C., C. Ogura, D.W. Meadows, A. Kane, L. Strommer, S. Fretz, D. Leonard, and A. McClung. 2005. Hawaii's Comprehensive Wildlife Conservation Strategy. Dept. of Land and Natural Resources. Honolulu, Hawaii. 722 p.
- Mobley, J.R., Jr., S.S. Spitz, K.A. Forney, R. Grotefendt, and P.H. Forestell. 2000. Distribution and abundance of odontocete species in Hawaiian waters: preliminary results of 1993-98 aerial surveys. Admin. Report LJ-00-14C. Southwest Fish. Sci. Centre, La Jolla, CA. 26 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.
- Monaco, C., J.M. Ibáñez, F. Carrión, and L.M. Tringali. 2016. Cetacean behavioural responses to noise exposure generated by seismic surveys: how to mitigate better? **Ann. Geophys.** 59(4):S0436. <http://dx.doi.org/doi:10.4401/ag-7089>.
- Moore, J.E. and J.P. Barlow. 2013. Declining abundance of beaked whales (family Ziphiidae) in the California Current large marine ecosystem. **PLoS One** 8(1):e52770.
- Moore, J. and J. Barlow. 2017. Population abundance and trend estimates for beaked whales and sperm whales in the California Current from ship-based visual line-transect survey data, 1991-2014. U.S. Dept. of Commerce, NOAA-National Marine Fisheries Service, La Jolla, CA. NOAA-TM-NMFS-SWFSC-585. 16 p.
- Moore, J.A., B.P. Wallace, R.L. Lewison, R. Zydelsis, T.M. Cox, and L.B. Crowder. 2009. A review of marine mammal, sea turtle and seabird bycatch in USA fisheries and the role of policy in shaping management. **Mar. Pol.** 33:435-451.
- Moore, S.E., K.M. Stafford, M.E. Dahlheim, C.G. Fox, H.W. Braham, J.J. Polovina, and D.E. Bain. 1998. Seasonal variation in reception of fin whale calls at five geographic areas in the North Pacific. **Mar. Mamm. Sci.** 14(3):617-627.
- Moore, S.E., K.M. Stafford, D.K. Mellinger, and C.G. Hildebrand. 2006. Listening for large whales in the offshore waters of Alaska. **BioScience** 56(1):49-55.
- Morejohn, G.V. 1979. The natural history of Dall's porpoise in the North Pacific Ocean. *In*: H.E. Winn and B.L. Olla (eds.), *Behavior of marine animals: current perspectives in research*, Vol. 3: Cetaceans. Plenum Press, New York, NY. 438 p.
- Morell, M., A. Brownlow, B. McGovern, S.A. Raverty, R.E. Shadwick, and M. André. 2017. Implementation of a method to visualize noise-induced hearing loss in mass stranded cetaceans. **Sci. Rep.** 7:41848 <https://doi.org/10.1038/srep41848>.
- Morin, P.A., C.S. Baker, R.S. Brewer, A.M. Burdin, M.L. Dalebout, J.P. Dines, I.D. Fedutin, O.A. Filatova, E. Hoyt, J.-L. Jung, M. Lauf, C.W. Potter, G. Richard, M. Ridgway, K.M. Robertson, and P.R. Wade. 2017.

- Genetic structure of the beaked whale genus *Berardius* in the North Pacific, with genetic evidence for a new species. **Mar. Mamm. Sci.** 33(1):96-111.
- Morreale, S., E. Standora, F. Paladino, and J. Spotila. 1994. Leatherback migrations along deepwater bathymetric contours. p.109 *In*: Schroeder, B.A. and B.E. Witherington (compilers), Proc. 13th Ann. Symp. Sea Turtle Biol. Conserv. NOAA Tech. Memo. NMFS-SEFSC-341. 281 p.
- Morris, C.J., D. Cote, B. Martin, and D. Kehler. 2018. Effects of 2D seismic on the snow crab fishery. **Fish. Res.** 197:67-77.
- Moulton, V.D. and M. Holst. 2010. Effects of seismic survey sound on cetaceans in the Northwest Atlantic. Environ. Stud. Res. Funds Rep. No. 182. St. John's, Nfld. 28 p.
- Muir, J.E., L. Ainsworth, R. Joy, R. Racca, Y. Bychkov, G. Gailey, V. Vladimirov, S. Starodymov, and K. Bröker. 2015. Distance from shore as an indicator of disturbance of gray whales during a seismic survey off Sakhalin Island, Russia. **Endang. Species. Res.** 29:161-178.
- Muir, J.E., L. Ainsworth, R. Racca, Y. Bychkov, G. Gailey, V. Vladimirov, S. Starodymov, and K. Broker. 2016. Gray whale densities during a seismic survey off Sakhalin Island, Russia. **Endang. Species Res.** 29(2):211-227.
- Mulsow, J., C.E. Schlundt, L. Brandt, and J.J. Finneran. 2015. Equal latency contours for bottlenose dolphins (*Tursiops truncatus*) and California sea lions (*Zalophus californianus*). **J. Acoust. Soc. Am.** 138(5): 2678-2691.
- Muñoz-Hincapié, M.F., D.M. Mora-Pinto, D.M. Palacios, E.R. Secchi, and A.A. Mignucci-Giannoni. 1998. First osteological record of the dwarf sperm whale in Colombia, with notes on the zoogeography of *Kogia* in South America. **Revista Acad. Colomb. Cien.** 22(84):433-444.
- Musick, J.A. and C.J. Limpus. 1997. Habitat utilization and migration in juvenile sea turtles. p. 137-163 *In*: P.L. Lutz and J.A. Musick (eds.), The biology of sea turtles. CRC Press, Boca Raton, FL. 432 p.
- Muto, M.M, V. T. Helker, R.P. Angliss, P.L. Boveng, J.M. Breiwick, M.F. Cameron, P.J. Clapham, S.P. Dahle, M.E. Dahlheim, B.S. Fadely, M.C. Ferguson, L.W. Fritz, R.C. Hobbs, Y.V. Ivashchenko, A.S. Kennedy, J.M. London, S.A. Mizroch, R.R. Ream, E.L. Richmond, K.E.W. Shelden, K.L. Sweeney, R.G. Towell, P.R. Wade, J.M. Waite, and A.N. Zerbini. 2018. Alaska marine mammal stock assessments, 2018. U.S. Dept. of Commerce, NOAA Tech. Memo. Draft accessed at <https://www.fisheries.noaa.gov/national/marine-mammal-protection/draft-marine-mammal-stock-assessment-reports>
- Myers, K.W., K.Y. Aydin, R.V. Walker, S. Fowler, and M.L. Dahlberg. 1996. Known ocean ranges of stocks of Pacific salmon and steelhead as shown by tagging experiments, 1956-1995. NPAFC Doc. 192 (FRI-UW-961). 4 p. + figures and appendixes.
- Nachtigall, P.E. and A.Y. Supin. 2013. A false killer whale reduces its hearing sensitivity when a loud sound is preceded by a warning. **J. Exp. Biol.** 216:3062-3070.
- Nachtigall, P.E. and A.Y. Supin. 2014. Conditioned hearing sensitivity reduction in the bottlenose dolphin (*Tursiops truncatus*). **J. Exp. Biol.** 217(15): 2806-2813.
- Nachtigall, P.E. and A.Y. Supin. 2015. Conditioned frequency-dependent hearing sensitivity reduction in the bottlenose dolphin (*Tursiops truncatus*). **J. Exp. Biol.** 218(7): 999-1005.
- Nachtigall, P.E. and A.Y. Supin. 2016. Hearing sensation changes when a warning predict a loud sound in the false killer whale (*Pseurorca crassidens*). p. 743-746 *In*: A.N. Popper and A. Hawkins (eds.), The effects of noise on aquatic life II. Springer, New York, NY. 1292 p.
- Nachtigall, P.E., A.Y. Supin, A.F. Pacini, and R.A. Kastelein. 2017. Four odontocete species change hearing levels when warned of impending loud sound. **Integrative Zool.** doi:10.1111/1749-4877.12286.

- National Academies of Sciences, Engineering, and Medicine. 2017. Approaches to understanding the cumulative effects of stressors on marine mammals. The National Academies Press. Washington, DC. 134 p.
- Nelms, S.E., W.E.D. Piniak, C.R. Weir, and B.J. Godley. 2016. Seismic surveys and marine turtles: an under-estimated global threat? **Biol. Conserv.** 193:49-65.
- Neave, F., T. Yonemori, and R.G. Bakkala. 1976. Distribution and origin of chum salmon in offshore waters of the North Pacific Ocean. International North Pacific Fisheries Commission.
- New, L.F., J. Harwood, L. Thomas, C. Donovan, J.S. Clark, G. Hastie, P.M. Thompson, B. Cheney, L. Scott-Hayward, and D. Lusseau. 2013a. Modelling the biological significance of behavioural change in coastal bottlenose dolphins in response to disturbance. **Funct. Ecol.** 27(2):314-322.
- New, L.F., D. Moretti, S.K. Hooker, D.P. Costa, and S.E. Simmons. 2013b. Using energetic models to investigate the survival and reproduction of beaked whales (family Ziphiidae). **PLoS ONE** 8(7):e68725.
- Nieukirk, S.L., D.K. Mellinger, S.E. Moore, K. Klinck, R.P. Dziak, and J. Goslin. 2012. Sounds from airguns and fin whales recorded in the mid-Atlantic Ocean, 1999–2009. **J. Acoust. Soc. Am.** 131(2):1102-1112.
- NMFS (National Marine Fisheries Service). 1998. Recovery plan for the blue whale (*Balaenoptera musculus*). Prepared by R.R. Reeves, P.J. Clapham, R.L. Brownell, Jr., and G.K. Silber for the Nat. Mar. Fish. Serv., Silver Spring, MD. 42 p.
- 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, 7 Feb.):9291-9298.
- NMFS. 2007. Conservation plan for the Eastern Pacific stock of northern fur seal (*Callorhinus ursinus*). National Marine Fisheries Service, Juneau, AK. 137 p.
- NMFS. 2008. Report on the bycatch of marine mammals and seabirds by the U.S. west coast groundfish fleet. West Coast Groundfish Observer Program, Northwest Fish. Sci. Center, Seattle, WA. 34 p.
- NMFS. 2011. U.S. National Bycatch Report [W.A. Karp, L.L. Desfosse, and S.G. Brooke, eds]. U.S. Dept. of Commerce, NOAA Tech. Memo. NMFS-F/SPO-117C. 508 p.
- NMFS. 2013a. Final recovery plan for the North Pacific right whale (*Eubalaena japonica*). National Marine Fisheries Service, Office of Protected Resources, Silver Spring, MD. 84 p.
- NMFS. 2013b. Effects of oil and gas activities in the Arctic Ocean: supplemental draft environmental impact statement. U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Office of Protected Resources. Accessed in April 2017 at <http://www.nmfs.noaa.gov/pr/permits/eis/arctic.htm>.
- NMFS. 2014. Designation of critical habitat for the Distinct Population Segments of yelloweye rockfish, canary rockfish, and bocaccio. Biological report. National Marine Fisheries Service, West Coast Region, Protected Resources Division. 51 p. + appendices. Accessed on 21 November 2018 at <https://repository.library.noaa.gov/view/noaa/18691>.
- NMFS. 2015a. Programmatic biological assessment on the effects of the fishery management plans for the Gulf of Alaska and Bering Sea/Aleutian Islands groundfish fisheries and the State of Alaska parallel groundfish fisheries on the endangered short-tailed albatross (*Phoebastria albatrus*) and the threatened Alaska-breeding population of the Steller's Eider (*Polysticta stelleri*). National Marine Fisheries Service, Alaska Region Sustainable Fisheries Division, Juneau, AK. 76 pp.
- NMFS. 2015b. Environmental assessment: proposed issuance of an incidental authorization to Lamont-Doherty Earth Observatory to take marine mammals by harassment incidental to a marine geophysical survey in the eastern Mediterranean Sea, Mid-November – December 2015. U.S. Dep. Comm. 38 p.

- NMFS. 2016a. Technical guidance for assessing the effects of anthropogenic sound on marine mammal hearing: underwater acoustic thresholds for onset of permanent and temporary threshold shifts. U.S. Department of Commerce, National Oceanic and Atmospheric Administration. 178 p.
- NMFS. 2016b. Endangered and threatened species; identification of 14 distinct population segments of the humpback whale (*Megaptera novaeangliae*) and revision of species-wide listing. Final Rule. **Fed. Regist.** 81(174, 8 Sept.):62260-62320.
- NMFS. 2016c. Environmental assessment: proposed issuance of an incidental authorization to Lamont-Doherty Earth Observatory to take marine mammals by harassment incidental to a marine geophysical survey over the Mid-Atlantic Ridge in the South Atlantic Ocean, January – March, 2016. U.S. Dept. of Commerce, 39 p.
- NMFS. 2016d. Environmental assessment: proposed issuance of an incidental authorization to Lamont-Doherty Earth Observatory to take marine mammals by harassment incidental to a marine geophysical survey in the Southeast Pacific Ocean, 2016-2017. U.S. Dept. of Commerce, 38 p.
- NMFS. 2017a. Recovery plan for the Southern Distinct Population Segment of eulachon (*Thaleichthys pacificus*). National Marine Fisheries Service, West Coast Region, Protected Resources Division, Portland, OR, 97232. 132 p. Accessed on 21 November 2018 at https://www.westcoast.fisheries.noaa.gov/protected_species/eulachon/pacific_eulachon.html.
- NMFS. 2017b. Environmental assessment: proposed issuance of an incidental authorization to Lamont-Doherty Earth Observatory to take marine mammals by harassment incidental to a marine geophysical survey in the Southwest Pacific Ocean, 2017/2018. U.S. Department of Commerce, 83 p.
- NMFS. 2017c. Environmental assessment: proposed issuance of an incidental authorization to the Scripps Institution of Oceanography to take marine mammals by harassment incidental to a low-energy geophysical survey in the northeastern Pacific Ocean, fall 2017. U.S. Department of Commerce, 73 p.
- NMFS. 2018a. 2018 revision to: technical guidance for assessing the effects of anthropogenic sound on marine mammal hearing (version 2.0). Underwater thresholds for onset of permanent and temporary threshold shifts. Office of Protected Resources Nat. Mar. Fish. Serv., Silver Spring, MD. 167 p.
- NMFS. 2018b. Endangered and threatened marine species. Accessed on 20 February 2017 at <http://www.nmfs.noaa.gov/pr/species/esa/>.
- NMFS. 2018c. Active and closed unusual mortality events. Accessed on 25 October 2018 at <https://www.fisheries.noaa.gov/national/marine-life-distress/active-and-closed-unusual-mortality-events>
- NMFS. 2018d. Recovery plan for the Southern Distinct Population Segment of North American green sturgeon (*Acipenser medirostris*). National Marine Fisheries Service, Sacramento, CA. 88 p. + appendix. Accessed on 21 November 2018 at <https://repository.library.noaa.gov/view/noaa/18695>.
- NMFS and USFWS (NMFS and U.S. Fish and Wildlife Service). 1998. Recovery plan for U.S. Pacific populations of the leatherback turtle (*Dermochelys coriacea*). Nat. Mar. Fish. Serv., Silver Spring, MD.
- NMFS and USFWS. 2013. Leatherback sea turtle (*Dermochelys coriacea*) 5-year review: summary and evaluation. Nat. Mar. Fish. Serv., Silver Spring, MD and U.S. Fish and Wildl. Serv., Jacksonville, FL 93 p.
- NOAA. 2018a. Pacific Decadal Oscillation (PDO). U.S. Department of Commerce, National Centers for Environmental Information, National Oceanic and Atmospheric Administration. Accessed on 14 November 2018 at <https://www.ncdc.noaa.gov/teleconnections/pdo/>.
- NOAA. 2018b. Species directory – ESA threatened & endangered. NOAA Fisheries, U.S. Department of Commerce, National Oceanic and Atmospheric Administration. Accessed on 14 November 2018 at <https://www.fisheries.noaa.gov/species-directory/threatened-endangered>.
- NOAA. 2018c. Essential Fish Habitat. NOAA Habitat Conservation, Habitat Protection. U.S. Department of Commerce, National Oceanic and Atmospheric Administration. Accessed 15 February 2018 at http://www.fpir.noaa.gov/HCD/hcd_efh.html.

- NOAA. 2018d. Essential Fish Habitat - Data Inventory. NOAA Habitat Conservation, Habitat Protection. U.S. Department of Commerce, National Oceanic and Atmospheric Administration. Accessed 15 February 2018 at <http://www.habitat.noaa.gov/protection/efh/newInv/index.html>.
- Norman, S.A., C.E. Bowlby, M.S. Brancato, J. Calambokidis, D. Duffield, J.P. Gearin, T.A. Gornall, M.E. Gosho, B. Hanson, J. Hodder, S. Jeffries, B. Lagerquist, D.M. Lambourn, B. Mate, B. Norberg, R.W. Osborne, J.A. Rash, S. Riemer, and J. Scordino. 2004. Cetacean strandings in Oregon and Washington between 1930 and 2002. **J. Cetac. Res. Manage.** 6(1):87-99.
- Norris, T.F., M. Mc Donald, and J. Barlow. 1999. Acoustic detections of singing humpback whales (*Megaptera novaeangliae*) in the eastern North Pacific during their northbound migration. **J. Acoust. Soc. Am.** 106(1):506-514.
- Norris, T., G. DeRango, R. DiGiovanni, and C. Field. 2015. Distribution of and threats to Guadalupe fur seals off the California coast. Poster presented at the Society of Marine Mammalogy Biennial meeting, San Francisco, CA.
- Nowacek, D.P., L.H. Thorne, D.W. Johnston, and P.L. Tyack. 2007. Responses of cetaceans to anthropogenic noise. **Mamm. Rev.** 37(2):81-115.
- Nowacek, D.P., A.I. Vedenev, B.L. Southall, and R. Racca. 2012. Development and implementation of criteria for exposure of western gray whales to oil and gas industry noise. p. 523-528 *In*: A.N. Popper and A. Hawkins (eds.), The effects of noise on aquatic life. Springer, New York, NY. 695 p.
- Nowacek, D.P., K. Bröker, G. Donovan, G. Gailey, R. Racca, R.R. Reeves, A.I. Vedenev, D.W. Weller, and B.L. Southall. 2013a. Responsible practices for minimizing and monitoring environmental impacts of marine seismic surveys with an emphasis on marine mammals. **Aquatic Mamm.** 39(4):356-377.
- Nowacek, D.P., K. Bröker, G. Donovan, G. Gailey, R. Racca, R.R. Reeves, A.I. Vedenev, D.W. Weller, and B.L. Southall. 2013b. Environmental impacts of marine seismic surveys with an emphasis on marine mammals. **Aquatic Mamm.** 39(4):356-377.
- Nowacek, D.P., C.W. Clark, P. Mann, P.J.O. Miller, H.C. Rosenbaum, J.S. Golden, M. Jasny, J. Kraska, and B.L. Southall. 2015. Marine seismic surveys and ocean noise: time for coordinated and prudent planning. **Front. Ecol. Environ.** 13(7):378-386.
- Nowacek, D.P., F. Christiansen, L. Bejder, J.A. Goldbogen, and A.S. Friedlaender. 2016. Studying cetacean behaviour: new technological approaches and conservation applications. **Animal Behav.** <http://dx.doi.org/doi:10.1016/j.anbehav.2016.07.019>.
- NRC (National Research Council). 2005. Marine mammal populations and ocean noise/Determining when noise causes biologically significant effects. U.S. Nat. Res. Council., Ocean Studies Board, Committee on characterizing biologically significant marine mammal behavior (Wartzok, D.W., J. Altmann, W. Au, K. Ralls, A. Starfield, and P.L. Tyack). Nat. Acad. Press, Washington, DC. 126 p.
- NSF (National Science Foundation). 2012. Record of Decision for marine seismic research funded by the National Science Foundation. June 2012. 41 p.
- NSF and USGS (NSF and U.S. Geological Survey). 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.
- Oakley, J.A., A.T. Williams, and T. Thomas. 2017. Reactions of harbour porpoise (*Phocoena phocoena*) to vessel traffic in the coastal waters of South Wales, UK. **Ocean & Coastal Manage.** 138:158-169.
- OBIS (Ocean Biogeographic Information System). 2018. Data from the Ocean Biogeographic Information System. Intergovernmental Oceanographic Commission of UNESCO. Accessed on 19 November 2018 at <http://www.iobis.org>.

- O'Brien, J.M., S. Beck, S.D. Berrow, M. André, M. van der Schaar, I. O'Connor, and E.P. McKeown. 2016. The use of deep water berths and the effect of noise on bottlenose dolphins in the Shannon Estuary cSAC. p. 775-783 *In: The effects of noise on aquatic life II*, Springer, New York, NY. 1292 p.
- O'Connor, A.J. 2013. Distributions and fishery associations of immature short-tailed albatrosses (*Phoebastria albatrus*) in the North Pacific. M.Sc. Thesis, Oregon State University, Corvallis, OR, USA.
- Odell, D.K. and K.M. McClune. 1999. False killer whale *Pseudorca crassidens* (Owen, 1846). p. 213-243 *In: S.H. Ridgway and R. Harrison (eds.), Handbook of marine mammals, Vol. 6: The second book of dolphins and the porpoises*. Academic Press, San Diego, CA. 486 p.
- OFWC (Oregon Fish and Wildlife Commission). 2013. Oregon Endangered Species Act listed threatened and endangered wildlife species: status summaries. 124 p.
- Oleson, E.M., J. Calambokidis, E. Falcone, G. Schorr, and J.A. Hildebrand. 2009. Acoustic and visual monitoring for cetaceans along the outer Washington coast. Naval Post Graduate School, Monterey, California. Rep. prepared for CNO(N45), Washington, D.C. 26 p. + appendix.
- Olson, P.A. 2009. Pilot whales *Globicephala melas* and *G. macrorhynchus*. p. 847-852 *In: W.F. Perrin, B. Würsig, and J.G.M. Thewissen (eds.), Encyclopedia of marine mammals, 2nd edit.* Academic Press, San Diego, CA. 1316 p.
- OOI (Ocean Observatories Initiative). 2018. Cabled Axial Seamount. Accessed in December 2018 at <https://ooi-website.whoi.edu/array/cabled-axial-seamount/>
- Oren, F. and A.P. DeVogelaere. 2014. A review of resource management strategies for protection of seamounts. Marine Sanctuaries Conservation Series ONMS-14-08. U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, Office of National Marine Sanctuaries, Silver Spring, MD. 52 p. Accessed on 15 November 2018 at https://repository.library.noaa.gov/view/noaa/17414/noaa_17414_DS1.pdf.
- Papale, E., M. Gamba, M. Perez-Gil, V.M. Martin, and C. Giacoma. 2015. Dolphins adjust species-specific frequency parameters to compensate for increasing background noise. **PLoS ONE** 10(4):e0121711. <http://dx.doi.org/doi:10.1371/journal.pone.0121711>.
- Pardo, M.A., T. Gerrodette, E. Beier, D. Gendron, K.A. Forney, S.J. Chivers, J. Barlow, and D.M. Palacios. 2015. Inferring cetacean population densities from the absolute dynamic topography of the ocean in a hierarchical Bayesian framework. **PLoS One** 10(3):e0120727. <https://doi.org/10.1371/journal.pone.0120727>.
- Parks, S.E. M. Johnson, D. Nowacek, and P.L. Tyack. 2011. Individual right whales call louder in increased environmental noise. **Biol. Lett.** 7(1):33-35.
- Parks, S.E., M.P. Johnson, D.P. Nowacek, and P.L. Tyack. 2012. Changes in vocal behaviour of North Atlantic right whales in increased noise. p. 317-320 *In: A.N. Popper and A. Hawkins (eds.), The effects of noise on aquatic life*. Springer, New York, NY. 695 p.
- Parks, S.E., K. Groch, P. Flores, R. Sousa-Lima, and I.R. Urazghildiiev. 2016a. Humans, fish, and whales: how right whales modify calling behavior in response to shifting background noise conditions. p. 809-813 *In: A.N. Popper and A. Hawkins (eds.), The effects of noise on aquatic life II*. Springer, New York, NY. 1292 p.
- Parks, S.E., D.A. Cusano, A. Bocconcelli, and A.S. Friedlaender. 2016b. Noise impacts on social sound production by foraging humpback whales. Abstr. 4th Int. Conf. Effects of Noise on Aquatic Life, July 2016, Dublin, Ireland.
- Parry, G.D., S. Heislors, G.F. Werner, M.D. Asplin, and A. Gason. 2002. Assessment of environmental effects of seismic testing on scallop fisheries in Bass Strait. Marine and Freshwater Resources Institute. Report No. 50.
- Paxton, A.B., J.C. Taylor, D.P. Nowacek, J. Dale, E. Cole, C.M. Voss, and C.H. Peterson. 2017. Seismic survey noise disrupted fish use of a temperate reef. **Mar. Policy** 78:68-73.

- Payne, R. 1978. Behavior and vocalizations of humpback whales (*Megaptera* sp.). In: K.S. Norris and R.R. Reeves (eds.), Report on a workshop on problems related to humpback whales (*Megaptera novaeangliae*) in Hawaii. MCC-77/03. Rep. from Sea Life Inc., Makapuu Pt., HI, for U.S. Mar. Mamm. Comm., Washington, DC.
- Payne, J.F., C.D. Andrews, J. Hanlon, and J. Lawson. 2015. Effects of seismic air-gun sounds on lobster (*Homarus americanus*): pilot laboratory studies with (i) a recorded track from a seismic survey and (ii) air-gun pulse exposures over 5 days. ESRF-NRC 197. 38 p.
- Pearcy, W.G. 1992. Ocean ecology of north Pacific salmonids, Univ. Washington Press, Seattle, WA. 179 p.
- 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. Envir. Res.** 38:93-113.
- Pelland, N.A., J.T. Sterling, M.A. Lea, N.A. Bond, R.R. Ream, C.M. Lee, and C.C. Eriksen. 2014. Female northern fur seals (*Callorhinus ursinus*) off the Washington (USA) coast: upper ocean variability and links to top predator behavior. **PLoS ONE** 9(8):e101268. <https://doi.org/10.1371/journal.pone.0101268>.
- Peña, H., N.O. Handegard, and E. Ona. 2013. Feeding herring schools do not react to seismic air gun surveys. **ICES J. Mar. Sci.** 70(6):1174-1180. <http://dx.doi.org/doi:10.1093/icesjms/fst079>.
- Pendoley, K. 1997. Sea turtles and management of marine seismic programs in Western Australia. **Petrol. Expl. Soc. Austral. J.** 25:8-16.
- Peng, C., X. Zhao, and G. Liu. 2015. Noise in the sea and its impacts on marine organisms. **Int. J. Environ. Res. Public Health** (12):12304-12323. <http://dx.doi.org/doi:10.3390/ijerph121012304>.
- Perrin, W.F. 2009. Pantropical spotted dolphin *Stenella attenuata*. p. 819-821 In: W.F. Perrin, B. Würsig, and J.G.M. Thewissen (eds.), Encyclopedia of marine mammals, 2nd edit. Academic Press, San Diego, CA. 1316 p.
- Perrin, W.F. and R.L. Brownell, Jr. 2009. Minke whales *Balaenoptera acutorostrata* and *B. bonaerensis*. p. 733-735 In: W.F. Perrin, B. Würsig, and J.G.M. Thewissen (eds.), Encyclopedia of marine mammals, 2nd edit. Academic Press, San Diego, CA. 1316 p.
- Perrin, W.F., C.E. Wilson, and F.I. Archer, II. 1994. Striped dolphin *Stenella coeruleoalba* (Meyen, 1833). p. 129-159 In: S. H. Ridgway and R. J. Harrison (eds.), Handbook of marine mammals, Vol. 5: The first book of dolphins. Academic Press, San Diego, CA. 416 p.
- Perry, S.L., D.P. DeMaster, and G.K. Silber. 1999a. The great whales: history and status of six species listed as endangered under the U.S. Endangered Species Act of 1973. **Mar. Fish. Rev.** 61(1):7-23.
- Perry, S.L., D.P. DeMaster, and G.K. Silber. 1999b. The fin whale. **Mar. Fish. Rev.** 61(1):44-51.
- Peterson, R.S., C.L. Hubbs, R.L. Gentry, and R.L. DeLong. 1968. The Guadalupe fur seal: habitat, behavior, population size, and field identification. **J. Mamm.** 49(4):665-675.
- Peterson, W., N. Bond, and M. Robert. 2016. The Blob is gone but has morphed into a strongly positive PDO/SST pattern. North Pacific Marine Science Organization. **PICES Press** 24(2):46-50.
- PFMC (Pacific Fishery Management Council). 2014. Appendix A to the Pacific Coast Salmon Fishery Management Plan. Pacific Fishery Management Council, Portland, OR.
- PFMC. 2016. Pacific coast groundfish fishery management plan for the California, Oregon and Washington groundfish fishery. Pacific Fishery Management Council, Portland, OR. 145 p. + appendices. Accessed in March 2017 at <http://www.pfcouncil.org/groundfish/fishery-management-plan/>.
- Philbrick, V.A., P.C. Fiedler, L.T. Balance, and D.A. Demer. 2003. Report of ecosystem studies conducted during the 2001 Oregon, California, and Washington (ORCAWALE) marine mammal survey on the research vessel *David Starr Jordan* and *McArthur*. NOAA Tech. Memo. NMFS-SWFSC-349. 50 p.

- Piatt, J., J. Wetzel, K. Bell, A. Degange, G. Balogh, G. Drew, T. Geernaert, C. Ladd, and G. Byrd. 2006. Predictable hotspots and foraging habitat of the endangered short-tailed albatross (*Phoebastria albatrus*) in the North Pacific: implications for conservation. **Deep Sea Res. Part II** 53:387-398.
- Pichegru, L., R. Nyengera, A.M. McInnes, and P. Pistorius. 2107. Avoidance of seismic survey activities by penguins. **Sci. Rep.** 7:16305. doi:10.1038/s41598-017-16569-x.
- Pierson, M.O., J.P. Wagner, V. Langford, P. Birnie, and M.L. Tasker. 1998. Protection from, and mitigation of, the potential effects of seismic exploration on marine mammals. Chapter 7 *In*: M.L. Tasker and C. Weir (eds.), Proc. Seismic Mar. Mamm. Worksh., London, UK., 23–25 June 1998.
- Pike, G.C. and I.B. MacAskie. 1969. Marine mammals of British Columbia. **Bull. Fish. Res. Board Can.** 171. 54 p.
- Piniak, W.E.D., D.A. Mann, S.A. Eckert, and C.A. Harms. 2012a. Amphibious hearing in sea turtles. p. 83-88. *In*: A.N. Popper and A. Hawkins (eds.), The effects of noise on aquatic life. Springer, New York. 695 p.
- Piniak, W.E.D., S.A. Eckert, C.A. Harms, and E.M. Stringer. 2012b. Underwater hearing sensitivity of the leatherback sea turtle (*Dermochelys coriacea*): assessing the potential effect of anthropogenic noise. U.S. Dept. of the Interior, Bureau of Ocean Energy Management, Headquarters, Herndon, VA. OCS Study BOEM 2012-01156. 35 p.
- Pirotta, E., R. Milor, N. Quick, D. Moretti, N. Di Marzio, P. Tyack, I. Boyd, and G. Hastie. 2012. Vessel noise affects beaked whale behavior: results of a dedicated acoustic response study. **PLoS ONE** 7(8):e42535. <http://dx.doi.org/doi:10.1371/journal.pone.0042535>.
- Pirotta, E., K.L. Brookdes, I.M. Graham, and P.M. Thompson. 2014. Variation in harbour porpoise activity in response to seismic survey noise. **Biol. Lett.** 10:20131090. <http://dx.doi.org/doi:10.1098/rsbl.2013.1090>.
- Pirotta, E., N.D. Merchant, P.M. Thompson, T.R. Barton, and D. Lusseau. 2015. Quantifying the effect of boat disturbance on bottlenose dolphin foraging activity. **Biol. Conserv.** 181:82-98.
- Pirotta, E., M. Mangel, D.P. Costa, B. Mate, J.A. Goldbogen, D.M. Palacios, L.A. Hüeckstädt, E.A. McHuron, L. Schwartz, and L. New. 2018. A dynamic state model of migratory behavior and physiology to assess the consequence of environmental variation and anthropogenic disturbance on marine vertebrates. **Am. Nat.** 191(2):E000-E000. <http://dx.doi.org/doi:10.5061/dryad.md416>.
- Pitman, R.L. 2009. Mesoplodont whales (*Mesoplodon* spp.) p. 721-726 *In*: W.F. Perrin, B. Würsig, and J.G.M. Thewissen (eds.), Encyclopedia of marine mammals, 2nd edit. Academic Press, San Diego, CA. 1316 p.
- Plotkin, P.T. 2003. Adult migrations and habitat use. p. 225-241 *In*: P.L. Lutz, J.A. Musick, and J. Wyneken (eds.), The biology of sea turtles. CRC Press, Boca Raton, FL. 455 p.
- Popov, V.V., A.Y. Supin, D. Wang, K. Wang, L. Dong, and S. Wang. 2011. Noise-induced temporary threshold shift and recovery in Yangtze finless porpoises *Neophocaena phocaenoides asiaeorientalis*. **J. Acoust. Soc. Am.** 130(1):574-584.
- Popov, V.V., A.Y. Supin, V.V. Rozhnov, D.I. Nechaev, E.V. Sysuyeva, V.O. Klishin, M.G. Pletenko, and M.B. Tarakanov. 2013. Hearing threshold shifts and recovery after noise exposure in beluga whales, *Delphinapterus leucas*. **J. Exp. Biol.** 216:1587-1596.
- Popov, V.V., D.I. Nechaev, E.V. Sysueva, V.V. *Delphinapterus leucas* Rozhnov, and A.Y. Supin. 2015. Spectrum pattern resolution after noise exposure in a beluga whale: evoked potential study. **J. Acoust. Soc. Am.** 138(1):377-388.
- Popov, V., A. Supin, D. Nechaev, E.V. Sysueva, and V. Rozhnov. 2016. Temporary threshold shifts in naïve and experienced belugas: Can dampening of the effects of fatiguing sounds be learned? p. 853-859 *In*: A.N. Popper and A. Hawkins (eds.), The effects of noise on aquatic life II. Springer, New York, NY. 1292 p.
- Popper, A.N. 2009. Are we drowning out fish in a sea of noise? **Mar. Scientist** 27:18-20.

- Popper, A.N. and M.C. Hastings. 2009a. The effects of human-generated sound on fish. **Integr. Zool.** 4:43-52.
- Popper, A.N. and M.C. Hastings. 2009b. The effects of anthropogenic sources of sound on fishes. **J. Fish Biol.** 75:455-489.
- Popper, A.N. and A.D. Hawkins. 2018. The importance of particle motion to fishes and invertebrates. **J. Acoust. Soc. Am.** 143(1):470-488.
- Popper, A.N., A.D. Hawkins, R.R. Fay, D.A. Mann, S. Bartol, T.J. Carlson, S. Coombs, W.T. Ellison, R.L. Gentry, M.B. Halvorsen, S. Løkkeborg, P.H. Rogers, B.L. Southall, D.G. Zeddies, and W.N. Tavolga. 2014. Sound exposure guidelines for fishes and sea turtles. A technical report prepared by ANSI-Accredited Standards Committee S3/SC1 and registered with ANSI. Springer Briefs in Oceanography. ASA Press—ASA S3/SC1.4 TR-2014. 75 p.
- Popper, A.N., T.J. Carlson, J.A. Gross, A.D. Hawkins, D.G. Zeddies, L. Powell, and J. Young. 2016. Effects of seismic air guns on pallid sturgeon and paddlefish. p. 871-878 *In*: A.N. Popper and A. Hawkins (eds.), The effects of noise on aquatic life II. Springer, New York, NY. 1292 p.
- PRFF (Portland Rose Festival Foundation). 2018. Rose Festival Fleet Week. Accessed on 19 November 2018 at <http://www.rosefestival.org/event/fleet-week>.
- Przeslawski, R., B. Bruce, A. Carroll, J. Anderson, R. Bradford, A. Durrant, M. Edmunds, S. Foster, Z. Huang, L. Hurt, M. Lansdell, K. Lee, C. Lees, P. Nichols, and S. Williams. 2016. Marine seismic survey impacts on fish and invertebrates: final report for the Gippsland Marine Environmental Monitoring Project. Record 2016/35. Geoscience Australia, Canberra.
- Przeslawski, R., Z. Huang, J. Anderson, A.G. Carroll, M. Edmunds, L. Hurt, and S. Williams. 2018. Multiple field-based methods to assess the potential impacts of seismic surveys on scallops. **Mar. Poll. Bull.** 129:750-761. doi: 10.1016/j.marpolbul.2017.10.066.
- Putland, R.L., N.D. Merchant, A. Farcas, and C.A. Radford. 2017. Vessel noise cuts down communication space for vocalizing fish and marine mammals. **Glob. Change Biol.** <https://doi.org/10.1111/gcb.13996>.
- Quick, N., L. Scott-Hayward, D. Sadykova, D. Nowacek, and A.J. Read. 2017. Effects of a scientific echo sounder on the behavior of short-finned pilot whales (*Globicephala macrorhynchus*). **Can. J. Fish. Aquat. Sci.** 74:716–726.
- Quinn, T.P. 2005. The behavior and ecology of Pacific salmon and trout. American Fisheries Society and University of Washington Press, Seattle, WA.
- Quinn, T.P. and K.W. Myers. 2004. Anadromy and the marine migrations of Pacific salmon and trout: Rounsefell revisited. **Rev. Fish Biol. Fish.** 14:421-442.
- Radford, A.N., E. Kerridge, and S.D. Simpson. 2014. Acoustic communication in a noisy world: Can fish compete with anthropogenic noise? **Behav. Ecol.** 25(5):1022-1030.
- Radford A.N., L. Lèbre, G. Lecaillon, S.L. Nedelec, and S.D. Simpson. 2016. Repeated exposure reduces the response to impulsive noise in European seabass. **Glob. Chang. Biol.** 22(10):3349–3360.
- Raine, A.F., N.D. Holmes, M. Travers, B.A. Cooper, and R.H. Day. 2017. Declining population trends of Hawaiian Petrel and Newell's Shearwater on the island of Kaua'i, Hawaii, USA. **Condor** 119:405-415.
- Rasmussen, K., J. Calambokidis, and G.H. Steiger. 2004. Humpback whales and other marine mammals off Costa Rica and surrounding waters, 1996–2003. Report of the Oceanic Society 2003 field season in cooperation with Elderhostel volunteers. Cascadia Research, Olympia, WA. 24 p.
- Rasmussen, K., D.M. Palacios, J. Calambokidis, M.T. Saborio, L. Dalla Rosa, E.R. Secchi, G.H. Steiger, J.M. Allen, and G.S. Stone. 2007. Southern Hemisphere humpback whales wintering off Central America: insights from water temperature into the longest mammalian migration. **Biol. Lett.** 3:302-305.

- Ream, R.R., J.T. Sterling, and T.R. Loughlin. 2005. Oceanographic features related to northern fur seal migratory movements. **Deep-Sea Res. II**: 823-843.
- Redfern, J.V., M.F. McKenna, T.J. Moore, J. Calambokidis, M.L. Deangelis, E.A. Becker, J. Barlow, K.A. Forney, P.C. Fiedler, and S.J. Chivers. 2013. Assessing the risk of ships striking large whales in marine spatial planning. **Conserv. Biol.** 27(2):292-302.
- Reeves, R.R., J. G. Mead, and S. Katona. 1978. The right whale, *Eubalaena glacialis*, in the western North Atlantic. **Rep. Int. Whal. Comm.** 28:303-12.
- Reeves, R.R., B.S. Stewart, P.J. Clapham, and J.A. Powell. 2002. Guide to marine mammals of the world. Chanticleer Press, New York, NY. 525 p.
- Reeves, R.R., B.D. Smith, E.A. Crespo, and G. Notarbartolo di Sciara. 2003. Dolphins, whales, and porpoises: 2002–2010 Conservation Action Plan for the World’s Cetaceans. IUCN/SSC Cetacean Specialist Group, Gland, Switzerland, and Cambridge, UK.
- Reichmuth, C., A. Ghoul, A. Rouse, J. Sills, and B. Southall. 2016. Low-frequency temporary threshold shift not measured in spotted or ringed seals exposed to single airgun impulses. **J. Acoust. Soc. Am.** 140(4):2646-2658.
- Reyes, J.C. 1991. The conservation of small cetaceans: a review. Report prepared for the Secretariat of the Convention on the Conservation of Migratory Species of Wild Animals. UNEP.
- Rice, D.W. 1974. Whales and whale research in the eastern North Pacific. p. 170-195 *In*: W.E. Schevill (ed.), The whale problem: a status report. Harvard Press, Cambridge, MA.
- Rice, D.W. 1978. The humpback whale in the North Pacific: distribution, exploitation and numbers. p. 29-44 *In*: K.S. Norris and R.R. Reeves (eds.), Report on a workshop on problems related to humpback whales (*Megaptera novaeangliae*) in Hawaii. NTIS PB 280 794, U.S. Dept. of Comm.
- Rice, D.W. 1989. Sperm whale *Physeter macrocephalus* Linnaeus, 1758. p. 177-233 *In*: S.H. Ridgway and R. Harrison (eds.), Handbook of marine mammals, Vol. 4: River dolphins and the larger toothed whales. Academic Press, San Diego, CA. 444 p.
- Rice, D.W. 1998. Marine mammals of the world, systematics and distribution. Spec. Publ. 4. Soc. Mar. Mammal., Allen Press, Lawrence, KS. 231 p.
- Rice, D.W. and C.H. Fiscus. 1968. Right whales in the south-eastern North Pacific. **Norsk Hvalfangst-tidende** 57:105-107.
- Rice, A.N., J.T. Tielens, B.J. Estabrook, C.A. Muirhead, A. Rahaman, M. Guerra, and C.W. Clark. 2014. Variation of ocean acoustic environments along the western North Atlantic coast: a case study in context of the right whale migration route. **Ecol. Inform.** 21:89-99.
- Richardson, A.J., R.J. Matear, and A. Lenton. 2017. Potential impacts on zooplankton of seismic surveys. CSIRO, Australia. 34 p.
- 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.
- 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 (Abstr.).
- Risch, D., P.J. Corkeron, W.T. Ellison, and S.M. Van Parijs. 2012. Changes in humpback whale song occurrence in response to an acoustic source 200 km away. **PLoS One** 7:e29741. <http://dx.doi.org/doi:10.1371/journal.pone.0029741>.
- Risch, D., P.J. Corkeron, W.T. Ellison, and S.M. Van Parijs. 2014. Formal comment to Gong et al.: Ecosystem scale acoustic sensing reveals humpback whale behavior synchronous with herring spawning processes and

- re-evaluation finds no effect of sonar on humpback song occurrence in the Gulf of Maine in fall 2006. **PLoS One** 9(10):e109225. <http://dx.doi.org/doi:10.1371/journal.pone.0109225>.
- Roberts, L. and M. Elliott. 2017. Good or bad vibrations? Impacts of anthropogenic vibration on the marine epibenthos. **Total Environ.** 595:255-268.
- Robertson, F.C., W.R. Koski, T.A. Thomas, W.J. Richardson, B. Würsig, and A.W. Trites. 2013. Seismic operations have variable effects on dive-cycle behavior of bowhead whales in the Beaufort Sea. **Endang. Species Res.** 21:143-160.
- Roe, J.H., S.J. Morreale, F.V. Paladino, G.L. Shillinger, S.R. Benson, S.A. Eckert, H. Bailey, P.S. Tomillo, S.J. Bograd, T. Eguchi, P.H. Dutton, J.A. Seminoff, B.A. Block, and J.R. Spotila. 2014. Predicting bycatch hotspots for endangered leatherback turtles on longlines in the Pacific Ocean. **Proc. R. Soc. B** 281:20132559. <http://dx.doi.org/10.1098/rspb.2013.2559>.
- Rolland, R.M., S.E. Parks, K.E. Hunt, M. Castellote, P.J. Corkeron, D.P. Nowacek, S.K. Water, and S.D. Kraus. 2012. Evidence that ship noise increases stress in right whales. **Proc. R. Soc. B** 279:2363-2368.
- Ronald, K. and B.L. Gots. 2003. Seals: Phocidae, Otariidae, and Odobenidae. p. 789-854 In: G.A. Feldhamer, B.C. Thompson, and J.A. Chapman (eds.), *Wild mammals of North America: biology, management, and conservation*, 2nd edit. John Hopkins University Press, Baltimore, MD.
- Rowlett, R.A., G.A. Green, C.E. Bowlby, and M.A. Smultea. 1994. The first photographic documentation of a northern right whale off Washington State. **Northwest. Nat.** 75:102-104.
- RPS. 2012a. Protected species mitigation and monitoring report; Cascadia Subduction Margin Geohazards Grays Harbor, Washington. Rep. by RPS, Houston, TX, for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and National Science Foundation, Arlington, VA. 98 p.
- RPS. 2012b. Draft protected species mitigation and monitoring report; Juan de Fuca Plate Evolution and Hydration in the northeast Pacific Ocean. Rep. by RPS, Houston, TX, for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and National Science Foundation, Arlington, VA. 74 p.
- RPS. 2012c. Protected species mitigation and monitoring report; Cascadia Thrust Zone Structures in the northeast Pacific Ocean. Rep. by RPS, Houston, TX, for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and National Science Foundation, Arlington, VA. 56 p.
- RPS. 2014a. Final environmental assessment for seismic reflection scientific research surveys during 2014 and 2015 in support of mapping the U.S. Atlantic seaboard extended continental margin and investigating tsunami hazards. Rep. from RPS for United States Geological Survey, August 2014. Accessed in March 2017 at <http://www.nsf.gov/geo/oce/envcomp/usgssurveyfinalea2014.pdf>.
- RPS. 2014b. Draft protected species mitigation and monitoring report: U.S. Geological Survey 2-D seismic reflection scientific research survey program: mapping the U.S. Atlantic seaboard extended continental margin and investigating tsunami hazards, in the northwest Atlantic Ocean, Phase 1, 20 August 2014–13 September 2014, R/V *Marcus G. Langseth*. Rep. from RPS, Houston, TX, for Lamont-Doherty Earth Observatory of Columbia University, Palisades, NY.
- RPS. 2015. Protected species mitigation and monitoring report: East North American Margin (ENAM) 2-D seismic survey in the Atlantic Ocean off the coast of Cape Hatteras, North Carolina, 16 September–18 October 2014, R/V *Marcus G. Langseth*. Rep. from RPS, Houston, TX, for Lamont-Doherty Earth Observatory of Columbia University, Palisades, NY.
- Sairanen, E.E. 2014. Weather and ship induced sounds and the effect of shipping on harbor porpoise (*Phocoena phocoena*) activity. M.Sc. Thesis, University of Helsinki. 67 p.
- Salden, D.R. 1993. Effects of research boat approaches on humpback whale behavior off Maui, Hawaii, 1989–1993. p. 94 In: *Abstr. 10th Bienn. Conf. Biol. Mar. Mamm.*, Galveston, TX, Nov. 1993. 130 p.

- Salden, D.R., L.M. Herman, M. Yamaguchik, and F. Sato. 1999. Multiple visits of individual humpback whales (*Megaptera novaeangliae*) between the Hawaiian and Japanese winter grounds. **Can. J. Zool.** 77(3):504-508.
- SAU (Sea Around Us). 2016. Catches by taxon in the non-EEZ waters of the Pacific, Northeast. Sea Around Us, Fisheries, Ecosystems & Biodiversity. Accessed on 16 November 2018 at <http://www.seararoundus.org/data/#/highseas/67?chart=catch-chart&dimension=taxon&measure=tonnage&limit=10>.
- Scammon, C.M. 1874. The marine mammals of the north-western coast of North America described and illustrated together with an account of the American whale fishery. John H. Carmany and Co., San Francisco, CA. 319 p. [Reprinted in 1968 by Dover Publications, Inc., New York.]
- Scarff, J.E. 1986. Historic and present distribution of the right whale, *Eubalaena glacialis*, in the eastern North Pacific south of 50°N and east of 180°W. **Rep. Int. Whal. Comm. Spec. Iss.** 10:43-63.
- Scarff, J.E. 1991. Historic distribution and abundance of the right whale, *Eubalaena glacialis*, in the North Pacific, Bering Sea, Sea of Okhotsk and Sea of Japan from the Maury Whale Charts. **Rep. Int. Whal. Comm.** 41:467-487.
- Schlundt, C.E., J.J. Finneran, D.A. Carder, and S.H. Ridgway. 2016. Temporary shift in masking hearing thresholds of bottlenose dolphins, *Tursiops truncatus*, and white whales, *Delphinapterus leucas*, after exposure to intense tones. p. 987-991 In: A.N. Popper and A. Hawkins (eds.), The effects of noise on aquatic life II. Springer, New York, NY. 1292 p.
- Scholik-Schlomer, A. 2015. Where the decibels hit the water: perspectives on the application of science to real-world underwater noise and marine protected species issues. **Acoustics Today** 11(3):36-44.
- Sciacca, V., S. Viola, S. Pulvirenti, G. Riccobene, F. Caruso, E. De Domenico, and G. Pavan. 2016. Shipping noise and seismic airgun surveys in the Ionian Sea: potential impact on Mediterranean fin whale. Proceedings of Meetings on Acoustics 4ENAL 27(1):040010. <http://dx.doi.org/doi:10.1121/2.0000311>.
- Scott, T.M. and S.S. Sadove. 1997. Sperm whale, *Physeter macrocephalus*, sightings in the shallow shelf waters off Long Island, New York. **Mar. Mamm. Sci.** 13(2):317-321.
- Seafair. 2018. Seafair Fleet Week and Boeing Maritime Celebration. Accessed on 19 November 2018 at <https://www.seafair.com/events/2018/fleet-week>.
- Sears, R. and W.F. Perrin. 2009. Blue whale *Balaenoptera musculus*. p. 120-124 In: W.F. Perrin, B. Würsig, and J.G.M. Thewissen (eds.), Encyclopedia of marine mammals, 2nd edit. Academic Press, San Diego, CA. 1316 p.
- Sergeant, D.E. 1977. Stocks of fin whales *Balaenoptera physalus* L. in the North Atlantic Ocean. **Rep. Int. Whal. Comm.** 27:460-473.
- Sidorovskaia, N., B. Ma, A.S. Ackleh, C. Tiemann, G.E. Ioup, and J.W. Ioup. 2014. Acoustic studies of the effects of environmental stresses on marine mammals in large ocean basins. p. 1155 In: AGU Fall Meeting Abstracts, Vol. 1.
- Sierra-Flores R., T. Attack, H. Migaud, and A. Davie. 2015. Stress response to anthropogenic noise in Atlantic cod *Gadus morhua* L. **Aquacult. Eng.** 67:67-76.
- Sills, J.M., B.L. Southall, and C. Reichmuth. 2017. The influence of temporally varying noise from seismic air guns on the detection of underwater sounds by seals. **J. Acoust. Soc. Am.** 141(2):996-1008.
- 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., S.J. Dolman, M. Jasny, E.C.M. Parsons, L. Weilgart, A.J. Wright, and R. Leaper. 2014. Marine noise pollution – Increasing recognition but need for more practical action. **J. Ocean Tech.** 9:71-90.
- Simons, T.R. and C.N. Hodges. 1998. Hawaiian Petrel (*Pterodroma sandwichensis*), version 2.0. In A.F. Poole and F.B. Gill (eds.) *The Birds of North America*. Cornell Lab of Ornithology, Ithaca, NY, USA. <https://doi.org/10.2173/bna.345>.
- SIO (Scripps Institute of Oceanography). n.d. Monitoring for protected species during a low-energy marine geophysical survey by the R/V Roger *Revelle* in the northeastern Pacific Ocean September-October 2017. Report available from Scripps Institute of Oceanography, 9500 Gilman Drive, La Jolla, California, 92093-0214. 84 p.
- Širović, A., E.M. Oleson, J. Calambokidis, S. Baumann-Pickering, A. Cummins, S. Kerosky, L. Roche, A. Simonis, S.M. Wiggins, and J.A. Hildebrand. 2012. Acoustic monitoring for marine mammals off Washington. In: E. Oleson and J. Hildebrand (eds.), *Marine mammal demographics off the outer Washington coast and near Hawaii*. Prepared for U.S. Navy. Naval Postgraduate School, Monterey, CA. NPS-OC-12-001CR April 2012. 69 p.
- Širović, A., S.C. Johnson, L.K. Roche, L.M. Varga, S.M. Wiggins, and J.A. Hildebrand. 2014. North Pacific right whales (*Eubalaena japonica*) recorded in the northeastern Pacific Ocean in 2013. **Mar. Mammal Sci.** <http://dx.doi.org/10.1111/mms.12189>.
- Solé, M., M. Lenoir, M. Durfort, M. López-Bejar, A. Lombarte, M. van der Schaaer, and M. André. 2013a. Does exposure to noise from human activities compromise sensory information from cephalopod statocysts? **Deep-Sea Res. II** 95:160-181.
- Solé, M. M. Lenoir, M. Durfort, M. López-Bejar, A. Lombarte, and M. André. 2013b. Ultrastructural damage of *Loligo vulgaris* and *Illex coindetii* statocysts after low frequency sound exposure. **PLoS One** 8(10):e78825. doi:10.1371/journal.pone.0078825.
- Solé, M., P. Sigray, M. Lenoir, M. van der Schaar, E. Lalander, and M. André. 2017. Offshore exposure experiments on cuttlefish indicate received sound pressure and particle motion levels associated with acoustic trauma. **Sci. Rep.** 7:45899. <http://dx.doi.org/doi:10.1038/srep45899>.
- 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.
- Southall, B.L., T. Rowles, F. Gulland, R.W. Baird, and P.D. Jepson. 2013. Final report of the Independent Scientific Review Panel investigating potential contributing factors to a 2008 mass stranding of melon-headed whales (*Peponocephala electra*) in Antsohihy, Madagascar. Accessed in March 2017 at http://www.agriculturedefensecoalition.org/sites/default/files/file/us_navy_new/271S_8_2013_Independent_Scientific_Review_Panel_Contributing_Factors_Mass_Whale_Stranding_Madagascar_September_25_2013_Final_Report.pdf.
- Southall, B.L., D.P. Nowacek, P.J.O. Miller, and P.L. Tyack. 2016. Experimental field studies to measure behavioral responses of cetaceans to sonar. **Endang. Species Res.** 31:293-315.
- Spear, L.B., D.G. Ainley, N. Nur, and S.N.G. Howell. 1995. Population size and factors affecting at-sea distributions of four endangered Procellariids in the Tropical Pacific. **Condor** 97(30):613-638.
- Spotila, J.R., R.D. Reina, A.C. Steyermark, P.T. Plotkin, and F.V. Paladino. 2000. Pacific leatherback turtles face extinction. **Nature** 405:529-530.
- Stacey, P.J. and R.W. Baird. 1991. Status of the false killer whale, *Pseudorca crassidens*, in Canada. **Can. Field-Nat.** 105(2):189-197.
- Stafford, K.M. 2003. Two types of blue whale calls recorded in the Gulf of Alaska. **Mar. Mamm. Sci.** 19(4):682-693.

- Stafford, K.M., C.G. Fox, and D.S. Clark. 1998. Long-range acoustic detection and localization of blue whale calls in the northeast Pacific Ocean. **J. Acoust. Soc. Am.** 104(6):3616-3625.
- Stafford, K.M., S.L. Niekirk, and C.G. Fox. 1999. Low-frequency whale sounds recorded on hydrophones moored in the eastern tropical Pacific. **J. Acoust. Soc. Am.** 106(6):3687-3698.
- Stafford, K.M., S.L. Niekirk, and C.G. Fox. 2001. Geographic and seasonal variation of blue whale calls in the North Pacific. **J. Cetac. Res. Manage.** 3(1):65-76.
- Stafford, K.M., D.K. Mellinger, S.E. Moore, and C.G. Fox. 2007. Seasonal variability and detection range modeling of baleen whale calls in the Gulf of Alaska, 1999–2002. **J. Acoust. Soc. Am.** 122(6):3378-3390.
- Stafford, K.M., J.J. Citta, S.E. Moore, M.A. Daher, and J.E. George. 2009. Environmental correlates of blue and fin whale call detections in the North Pacific Ocean from 1997 to 2002. **Mar. Ecol. Progr. Ser.** 395:37-53.
- Stewart, B.S. and R.L. DeLong. 1995. Double migrations of the northern elephant seal, *Mirounga angustirostris*. **J. Mammal.** 76(1):196-205.
- Stewart, B.S. and H.R. Huber. 1993. *Mirounga angustirostris*. **Mammal. Species** 449:1-10.
- Stewart, B.S. and S. Leatherwood. 1985. Minke whale *Balaenoptera acutorostrata* Lacépède, 1804. p. 91-136 *In*: S.H. Ridgway and R. Harrison (eds.), Handbook of marine mammals, Vol. 3: The sirenians and baleen whales. Academic Press, London, UK. 362 p.
- Stewart, B.S., P.K. Yochem, R.L. DeLong, and G.A. Antonelis Jr. 1987. Interactions between Guadalupe fur seals and California sea lions at San Nicolas and San Miguel Islands, California. p. 103-106 *In*: J.P. Croxall and R.L. Gentry (eds.), Status, biology, and ecology of fur seals. NOAA Tech. Rep. NMFS 51. National Marine Fisheries Service. 212 p.
- Stewart, B.S., B.J. Le Boeuf, P.K. Yochem, H.R. Huber, R.L. DeLong, R.J. Jameson, W. Sydeman, and S.G. Allen. 1994. History and present status of the northern elephant seal population. *In*: B.J. Le Boeuf and R.M. Laws (eds.), Elephant seals. Univ. Calif. Press, Los Angeles, CA.
- Stinson, M.L. 1984. Biology of sea turtles in San Diego Bay, California, and in the northeastern Pacific Ocean. M.Sc. Thesis, San Diego State University. 578 p.
- Stone, C.J. 2015. Marine mammal observations during seismic surveys from 1994–2010. JNCC Rep. No. 463a. 64 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.
- Streever, B., S.W. Raborn, K.H. Kim, A.D. Hawkins, and A.N. Popper. 2016. Changes in fish catch rates in the presence of air gun sounds in Prudhoe Bay, Alaska. **Arctic [Suppl. 1]** 69(4):346–358.
- Supin, A., V. Popov, D. Nechaev, E.V. Sysueva, and V. Rozhnov. 2016. Is sound exposure level a convenient metric to characterize fatiguing sounds? A study in beluga whales. p. 1123-1129 *In*: A.N. Popper and A. Hawkins (eds.), The effects of noise on aquatic life II. Springer, New York, NY. 1292 p.
- Suryan, R.M., K.S. Dietrich, E.F. Melvin, G.R. Balogh, F. Sato, and K. Ozaki. 2007. Migratory routes of short-tailed albatrosses: use of exclusive economic zones of North Pacific Rim countries and spatial overlap with commercial fisheries in Alaska. **Biol. Conserv.** 137(3):450-460.
- Sychenko, O., G. Gailey, R. Racca, A. Rutenko, L. Aerts, and R. Melton. 2017. Gray whale abundance and distribution relative to three seismic surveys near their feeding habitat in 2015. Abstract and presentation at the Society for Marine Mammalogy's 22nd Biennial Conference on the Biology of Marine Mammals, 22-27 October, Halifax, Nova Scotia, Canada.
- Teilmann, J., D.M. Wisniewska, M. Johnson, L.A. Miller, U. Siebert, R. Dietz, S. Sveegaard, A. Galatius, and P.T. Madsen. 2015. Acoustic tags on wild harbour porpoises reveal context-specific reactions to ship noise. *In*: 18. Danske Havforskermøde 2015, 28-30 January 2015.

- Tenessen, J.B. and S.E. Parks. 2016. Acoustic propagation modeling indicates vocal compensation in noise improves communication range for North Atlantic right whales. **Endang. Species Res.** 30:225-237.
- Terhune, J.M. and T. Bosker. 2016. Harp seals do not increase their call frequencies when it gets noisier. p. 1149-1153 *In*: A.N. Popper and A. Hawkins (eds.), *The effects of noise on aquatic life II*. Springer, New York, NY. 1292 p.
- Thode, A.M., K.H. Kim, S.B. Blackwell, C.R. Greene, Jr., C.S. Nations, T.L. McDonald, and A.M. Macrander. 2012. Automated detection and localization of bowhead whale sounds in the presence of seismic airgun surveys. **J. Acoust. Soc. Am.** 131(5):3726-3747.
- 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. *Abstr. World Mar. Mamm. Sci. Conf., Monaco*.
- Thompson, P.M., K.L. Brookes, I.M. Graham, T.R. Barton, K. Needham, G. Bradbury, and N.D. Merchant. 2013. Short-term disturbance by a commercial two-dimensional seismic survey does not lead to long-term displacement of harbour porpoises. **Proc. Royal Soc. B** 280: 20132001.
- Tolstoy, M., J. Diebold, L. Doermann, S. Nooner, S.C. Webb, D.R. Bohlenstiehl, T.J. Crone, and R.C. Holmes. 2009. Broadband calibration of R/V *Marcus G. Langseth* four-string seismic sources. **Geochem. Geophys. Geosyst.** 10, Q08011. <https://doi.org/10.1029/2009GC002451>.
- Tougaard, J., A.J. Wright, and P.T. Madsen. 2015. Cetacean noise criteria revisited in light of proposed exposure limits for harbour porpoises. **Mar. Poll. Bull.** 90(1-2):196-208.
- Tougaard, J., A.J. Wright, and P.T. Madsen. 2016. Noise exposure criteria for harbor porpoises. p. 1167-1173 *In*: A.N. Popper and A. Hawkins (eds.), *The effects of noise on aquatic life II*. Springer, New York, NY. 1292 p.
- Tyack, P.L. and V.M. Janik. 2013. Effects of noise on acoustic signal production in marine mammals. p. 251-271 *In*: H. Brumm (ed.), *Animal communication and noise*. Springer, Berlin, Heidelberg, Germany. 453 p.
- Tynan, C.T., D.P. DeMaster, and W.T. Peterson. 2001. Endangered right whales on the southeastern Bering Sea shelf. **Science** 294(5548):1894.
- Tyson, R.B., W.E.D. Piniak, C. Domit, D. Mann, M. Hall, D.P. Nowacek, and M.M.P.B. Fuentes. 2017. Novel bio-logging tool for studying fine-scale behaviors of marine turtles in response to sound. **Front. Mar. Sci.** 4:219. <http://dx.doi.org/doi:10.3389/fmars.2017.00219>.
- UNEP-WCMC (United Nations Environment Programme-World Conservation Monitoring Centre). 2018. Convention on International Trade in Endangered Species of Wild Flora and Fauna. Appendices I, II, and III. Accessed in November 2018 at <http://www.cites.org/eng/app/appendices.php>.
- USCG (United States Coast Guard). 2018. Amver density plot display. United States Coast Guard, U.S. Dept. of Homeland Security. Accessed on 19 November 2018 at <http://www.amver.com/Reports/DensityPlots>.
- USFWS. 2005. Regional seabird conservation plan, Pacific region. Portland, Oregon: U.S. Fish and Wildlife Service, Migratory Birds and Habitats Program, Pacific Region. 264 p.
- USFWS. 2008. Short-tailed albatross recovery plan. Anchorage, AK. 105 p.
- USFWS. 2017. Biological Opinion regarding the Effects of the Continued Operation of the Pacific Coast Groundfish Fishery as Governed by the Pacific Coast Groundfish Fishery Management Plan and Implementing regulations at 50 CFR Part 660 by the National Marine Fisheries Service on California Least Tern, Southern Sea Otter, Bull Trout, Marbled Murrelet, and Short-tailed Albatross (FWS reference number 01EOFW00-2017-F-0316). U.S. Fish and Wildlife Service, Oregon Fish and Wildlife Office, Portland, OR. 59 p. + appendices.

- USN (U.S. Navy). 2010. NAVSEA NUWC Keyport Range Complex Extension Environmental Impact Statement/Overseas Environmental Impact Statement. Appendix D: Marine mammal densities and depth distribution. Prepared by Naval Facilities Engineering Command Northwest for Naval Undersea Warfare Center, Keyport.
- USN. 2015. Final environmental impact statement/overseas environmental impact statement for northwest training and testing activities. U.S. Dept. of the Navy in cooperation with the National Marine Fisheries Service and United States Coast Guard. 1004 p. Accessed in March 2017 at <http://nwtteis.com/DocumentsandReferences/NWTTDocuments/FinalEISOEIS.aspx>.
- USN. 2017. Criteria and thresholds for U.S. Navy Acoustic and Explosive Effects Analysis (Phase III). Technical report prepared by the U.S. Navy.
- USN. 2018. U.S. Navy Marine Species Density Database Phase III for the Northwest Training and Testing Study Area. NAVFAC Pacific Technical Report. Naval Facilities Engineering Command Pacific, Pearl Harbor, HI. 258 p.
- van Beest, F.M., J. Teilmann, L. Hermanssen, A. Galatius, L. Mikkelsen, S. Sveegaard, J.D. Balle, R. Dietz, J. Nabe-Nielsen. 2018. Fine-scale movement responses of free-ranging harbour porpoises to capture, tagging and short-term noise pulses from a single airgun. **R. Soc. Open Sci.** 5:170110. <http://dx.doi.org/doi:10.1098/rsos.170110>.
- Van der Wal, S., S.A. Eckert, J.O. Lopez-Plana, W. Hernandez, and K.L. Eckert. 2016. Innovative measures for mitigating potential impacts on sea turtles during seismic surveys. Paper SPE-179215-MS presented at the SPE International Conference and Exhibition on Health, Safety, Security, Environment, and Social Responsibility. 11–13 April 2016, Stavanger, Norway. 11 p.
- Vilela, R., U. Pena, R. Esteban, and R. Koemans. 2016. Bayesian spatial modeling of cetacean sightings during a seismic acquisition survey. **Mar. Poll. Bull.** 109(1):512-520.
- Von Sauner, A. and J. Barlow. 1999. A report of the Oregon, California and Washington line-transect experiment (ORCAWALE) conducted in west coast waters during summer/fall 1996. NOAA Tech. Memo. NMFS-SWFSC-264. Nat. Mar. Fish. Serv, Southwest Fish. Sci. Center, La Jolla, CA. 40 p.
- Wade, P.R. and T. Gerrodette. 1993. Estimates of cetacean abundance and distribution in the eastern tropical Pacific. **Rep. Int. Whal. Comm.** 43:477-493.
- Waite, J.M., K. Wynne, and D.K. Mellinger. 2003. Documented sighting of a North Pacific right whale in the Gulf of Alaska and post-sighting acoustic monitoring. **Northw. Nat.** 84:38-43.
- Wale, M.A., S.D. Simpson, and A.N. Radford. 2013a. Size-dependent physiological responses of shore crabs to single and repeated playback of ship noise. **Biol. Lett.** 9:20121194.
- Wale, M.A., S.D. Simpson, and A.N. Radford. 2013b. Noise negatively affects foraging and antipredator behaviour in shore crabs. **Anim. Behav.** 86:111-118.
- Walker, J.L., C.W. Potter, and S.A. Macko. 1999. The diets of modern and historic bottlenose dolphin populations reflected through stable isotopes. **Mar. Mamm. Sci.** 15(2):335-350.
- Wang, M.C., W.A. Walker, K.T. Shao, and L.S. Chou. 2002. Comparative analysis of the diets of pygmy sperm whales and dwarf sperm whales in Taiwanese waters. **Acta Zool. Taiwan** 13(2):53-62.
- 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. and K.E. Moore. 1982. An underwater acoustic survey for sperm whales (*Physeter catodon*) and other cetaceans in the southeast Caribbean. **Cetology** 46:1-7.
- Watkins, W.A., M.A. Daher, G.M. Reppucci, J.E. George, D.L. Martin, N.A. DiMarzio, and D.P. Gannon. 2000a. Seasonality and distribution of whale calls in the North Pacific. **Oceanography** 13:62-67.

- Watkins, W.A., J.E. George, M.A. Daher, K. Mullin, D.L. Martin, S.H. Haga, and N.A. DiMarzio. 2000b. Whale call data from the North Pacific, November 1995 through July 1999: occurrence of calling whales and source locations from SOSUS and other acoustic systems. Tech. Rep. WHOI-00-02. Woods Hole Oceanographic Inst., Woods Hole, MA. 160 p.
- WBRC (Washington Bird Records Committee). 2018. Summary of all WBRC decisions. Accessed on 20 November at <http://wos.org/records/votingsummary/>.
- Weilgart, L.S. 2007. A brief review of known effects of noise on marine mammals. **Int. J. Comp. Psychol.** 20:159-168.
- Weilgart, L.S. 2014. Are we mitigating underwater noise-producing activities adequately? A comparison of Level A and Level B cetacean takes. Working pap. SC/65b/E07. Int. Whal. Comm., Cambridge, UK. 17 p.
- Weilgart, L. 2017a. Din of the deep: noise in the ocean and its impacts on cetaceans. Pages 111-124 *In*: A. Butterworth (ed.), Marine mammal welfare human induced change in the marine environment and its impacts on marine mammal welfare. Springer.
- Weilgart, L.S. 2017b. The impact of ocean noise pollution on fish and invertebrates. Report for OceanCare, Switzerland. 23 p.
- Weir, C.R. 2007. Observations of marine turtles in relation to seismic airgun sound off Angola. **Mar. Turtle Newsl.** 116:17-20.
- Weir, C.R. and S.J. Dolman. 2007. Comparative review of the regional marine mammal mitigation guidelines implemented during industrial seismic surveys, and guidance towards a worldwide standard. **J. Int. Wildl. Law Policy** 10(1):1-27.
- 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.
- Wells, R.S. and M.D. Scott. 2009. Common bottlenose dolphin *Tursiops truncatus*. p. 249-255 *In*: W.F. Perrin, B. Würsig, and J.G.M. Thewissen (eds.), Encyclopedia of marine mammals, 2nd edit. Academic Press, San Diego, CA. 1316 p.
- Wensveen, P.J., L.A.E. Huijser, L. Hoek, and R.A. Kastelein. 2014. Equal latency contours and auditory weighting functions for the harbour porpoise (*Phocoena phocoena*). **J. Exp. Biol.** 217(3):359-369.
- Wensveen, P.J., A.M. von Benda-Beckmann, M.A. Ainslie, F.P.A. Lam, P.H. Kvadsheim, P.L. Tyack, and P.J.O. Miller. 2015. How effectively do horizontal and vertical response strategies of long-finned pilot whales reduce sound exposure from naval sonar? **Mar. Environ. Res.** 106:68-81.
- Whitehead, H. 2003. Sperm whales: social evolution in the ocean. University of Chicago Press, Chicago, IL. 431 p.
- Whitehead, H. 2009. Sperm whale *Physeter macrocephalus*. p. 1091-1097 *In*: W.F. Perrin, B. Würsig, and J.G.M. Thewissen (eds.), Encyclopedia of marine mammals, 2nd edit. Academic Press, San Diego, CA. 1316 p.
- Whitehead, H. and S. Waters. 1990. Social organization and population structure of sperm whales off the Galápagos Islands, Ecuador (1985–1987). **Rep. Int. Whal. Comm. Spec. Iss.** 12:249-257.

- Whitehead, H., S. Waters, and T. Lyrholm. 1992. Population structure of female and immature sperm whales (*Physeter macrocephalus*) off the Galápagos Islands. **Can. J. Fish. Aquatic Sci.** 49(1):78-84.
- Wiley, D.N., C.A. Mayo, E.M. Maloney, and M.J. Moore. 2016. Vessel strike mitigation lessons from direct observations involving two collisions between noncommercial vessels and North Atlantic right whales (*Eubaleana glacialis*). **Mar. Mammal Sci.** 32(4):1501-1509.
- Williams, T.M., W.A. Friedl, M.L. Fong, R.M. Yamada, P. Sideivy, and J.E. Haun. 1992. Travel at low energetic cost by swimming and wave-riding bottlenose dolphins. **Nature** 355(6363):821-823.
- Willis, K.L., J. Christensen-Dalsgaard, D.R. Ketten, and C.E. Carr. 2013. Middle ear cavity morphology is consistent with an aquatic origin for testudines. **PLoS One** 8(1):e54086. <http://dx.doi.org/doi:10.1371/journal.pone.0054086>.
- Winn, H.E. and N.E. Reichley. 1985. Humpback whale *Megaptera novaeangliae* (Borowski, 1781). p. 241-273 *In*: S.H. Ridgway and R. Harrison (eds.), Handbook of marine mammals, Vol. 3: The sirenians and baleen whales. Academic Press, London, UK. 362 p.
- Winsor, M.H., L.M. Irvine, and B.R. Mate. 2017. Analysis of the spatial distribution of satellite-tagged sperm whales (*Physeter macrocephalus*) in close proximity to seismic surveys in the Gulf of Mexico. **Aquatic Mamm.** 43(4):439-446.
- Wisniewska, D.M., M. Johnson, J. Teilmann, U. Siebert, A. Galatius, R. Dietz, and P.T. Madsen. 2018. High rates of vessel noise disrupt foraging in wild harbour porpoises (*Phocoena phocoena*). **Proc. R. Soc. B** 285: 20172314.
- Wittekind, D., J. Tougaard, P. Stilz, M. Dähne, K. Lucke, C.W. Clark, S. von Benda-Beckmann, M. Ainslie, and U. Siebert. 2016. Development of a model to assess masking potential for marine mammals by the use of airguns in Antarctic waters. p. 1243-1249 *In*: A.N. Popper and A. Hawkins (eds.), The effects of noise on aquatic life II. Springer, New York, NY. 1292 p.
- Wole, O.G. and E.F. Myade. 2014. Effect of seismic operations on cetacean sightings off-shore Akwa Ibom State, south-south, Nigeria. **Int. J. Biol. Chem. Sci.** 8(4):1570-1580.
- Wright, A.J. 2014. Reducing impacts of human ocean noise on cetaceans: knowledge gap analysis and recommendations. 98 p. World Wildlife Fund Global Arctic Programme, Ottawa, ON.
- Wright, A.J. and A.M. Consentino. 2015. JNCC guidelines for minimizing the risk of injury and disturbance to marine mammals from seismic surveys: we can do better. **Mar. Poll. Bull.** 100(1):231-239. <http://dx.doi.org/doi:10.1016/j.marpolbul.2015.08.045>.
- Wright, A.J. and L.A. Kyhn. 2014. Practical management of cumulative anthropogenic impacts for working marine examples. **Conserv. Biol.** 29(2):333-340. <https://doi.org/10.1111/cobi.12425>.
- Wright, A.J., T. Deak, and E.C.M. Parsons. 2011. Size matters: management of stress responses and chronic stress in beaked whales and other marine mammals may require larger exclusion zones. **Mar. Poll. Bull.** 63(1-4):5-9.
- Würsig, B., S.K. Lynn, T.A. Jefferson, and K.D. Mullin. 1998. Behaviour of cetaceans in the northern Gulf of Mexico 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. Assess.** 134(1-3):45-73. <http://dx.doi.org/doi:10.1007/s10661-007-9809-9>.
- 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. Assess.** 134(1-3): 93-106. <http://dx.doi.org/doi:10.1007/s10661-007-9810-3>.
- Yochem, P.K. and S. Leatherwood. 1985. Blue whale. p. 193-240 *In*: S.H. Ridgway and R. Harrison (eds.), Handbook of marine mammals, Vol. 3: The sirenians and baleen whales. Academic Press, New York, NY. 362 p.
- 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.
- Yu, Z.H., H.S. Yang, B.Z. Liu, Q. Xu, K. Xing, L.B. Zhang. 2010. Growth, survival and immune activity of scallops, *Chlamys farreri* Jones et Preston, compared between suspended and bottom culture in Haizhou Bay, China. **Aquacult. Res.** 41:814-827.

LIST OF APPENDICES

APPENDIX A: DETERMINATION OF MITIGATION ZONES

APPENDIX B: MARINE MAMMAL TAKE CALCULATIONS

APPENDIX C: ENSONIFIED AREAS FOR MARINE MAMMAL TAKE CALCULATIONS

APPENDIX A: DETERMINATION OF MITIGATION ZONES

APPENDIX A: DETERMINATION OF MITIGATION ZONES

During the planning phase, mitigation zones for the proposed marine seismic surveys were calculated based on modeling by L-DEO for both the exclusion zones (EZ) for Level A takes and safety zones (160 dB re $1\mu\text{Pa}_{\text{rms}}$) for Level B takes. Received sound levels have been predicted by L-DEO's model (Diebold et al. 2010, provided as Appendix H in the PEIS) as a function of distance from the 36-airgun array, the 18-airgun array, and for a single 1900LL 40-in³ airgun, which would be used during power downs. The models used a 10-m tow depth for the 18-airgun array to be used during the 3-D survey, and a 12-m tow depth for the 36-airgun array to be used during the 2-D survey and the 40-in³ mitigation airgun. This modeling approach uses ray tracing for the direct wave traveling from the array to the receiver and its associated source ghost (reflection at the air-water interface in the vicinity of the array), in a constant-velocity half-space (infinite homogeneous ocean layer, unbounded by a seafloor). In addition, propagation measurements of pulses from the 36-airgun array at a tow depth of 6 m have been reported in deep water (~1600 m), intermediate water depth on the slope (~600–1100 m), and shallow water (~50 m) in the Gulf of Mexico (GoM) in 2007–2008 (Tolstoy et al. 2009; Diebold et al. 2010).

For deep water, the field measurements cannot be used readily to derive mitigation radii, as at those sites the calibration hydrophone was located at a roughly constant depth of 350–500 m, which may not intersect all the sound pressure level (SPL) isopleths at their widest point from the sea surface down to the maximum relevant water depth for marine mammals of ~2000 m. Figures 2 and 3 in Appendix H of the PEIS show how the values along the maximum SPL line that connects the points where the isopleths attain their maximum width (providing the maximum distance associated with each sound level) may differ from values obtained along a constant depth line. At short ranges, where the direct arrivals dominate and the effects of seafloor interactions are minimal, the data recorded at the deep and slope sites are suitable for comparison with modeled levels at the depth of the calibration hydrophone. At longer ranges, the comparison with the mitigation model—constructed from the maximum SPL through the entire water column at varying distances from the airgun array—is the most relevant. The results are summarized below.

In deep water, comparisons at short ranges between sound levels for direct arrivals recorded by the calibration hydrophone and model results for the same array tow depth are in good agreement (Fig. 12 and 14 in Appendix H of the PEIS). Consequently, isopleths falling within this domain can be predicted reliably by the L-DEO model, although they may be imperfectly sampled by measurements recorded at a single depth. At greater distances, the calibration data show that seafloor-reflected and sub-seafloor-refracted arrivals dominate, whereas the direct arrivals become weak and/or incoherent (Fig. 11, 12, and 16 in Appendix H of the PEIS). Aside from local topography effects, the region around the critical distance (~5 km in Fig. 11 and 12, and ~4 km in Fig. 16 in Appendix H of the PEIS) is where the observed levels rise closest to the mitigation model curve. However, the observed sound levels are found to fall almost entirely below the mitigation model curve (Fig. 11, 12, and 16 in Appendix H of the PEIS). Thus, analysis of the GoM calibration measurements demonstrates that although simple, the L-DEO model is a robust tool for conservatively estimating mitigation radii.

The proposed surveys would acquire data with the 36-airgun array at a maximum tow depth of 12 m (2-D survey) and an 18-airgun array at a tow depth of 10 m (3-D survey). For deep water (>1000 m), we use the deep-water radii obtained from L-DEO model results down to a maximum water depth of 2000 m for the 36-airgun (Fig. A-1) and 18-airgun (Fig. A-2) array. Measurements have not been reported for a 40-in³ airgun; thus, L-DEO model results are used to determine the 160-dB_{rms} radius for the 40-in³ airgun at a 12-m tow depth in deep water (Fig. A-3).

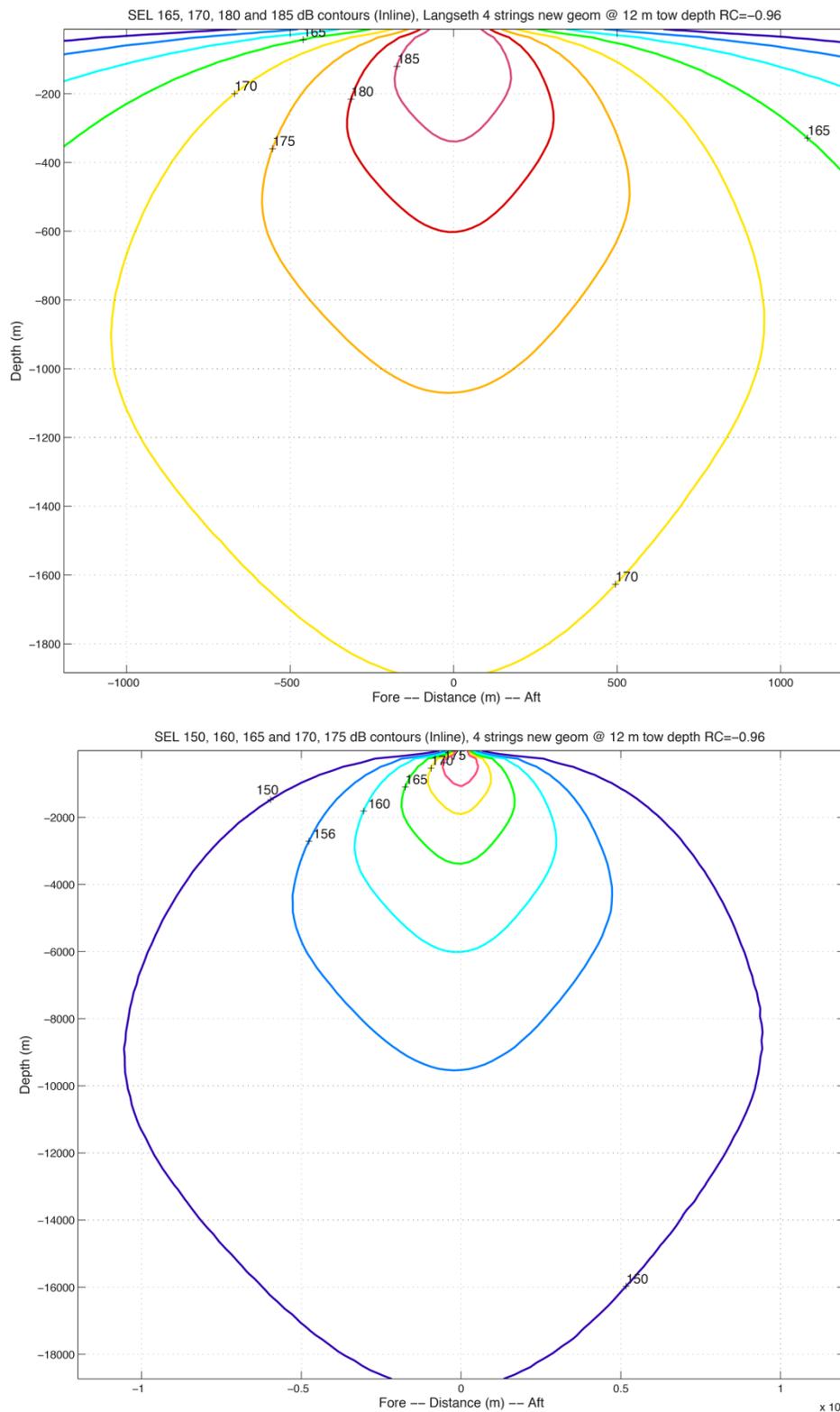


FIGURE A-1. Modeled deep-water received sound exposure levels (SELs) from the 36-airgun array at a 12-m tow depth planned for use during the 2-D survey in the Northeast Pacific Ocean. Received rms levels (SPLs) are expected to be ~10 dB higher. For example, the radius to the 150-dB SEL isopleth is a proxy for the 160-dB rms isopleth. The upper plot is a zoomed-in version of the lower plot.

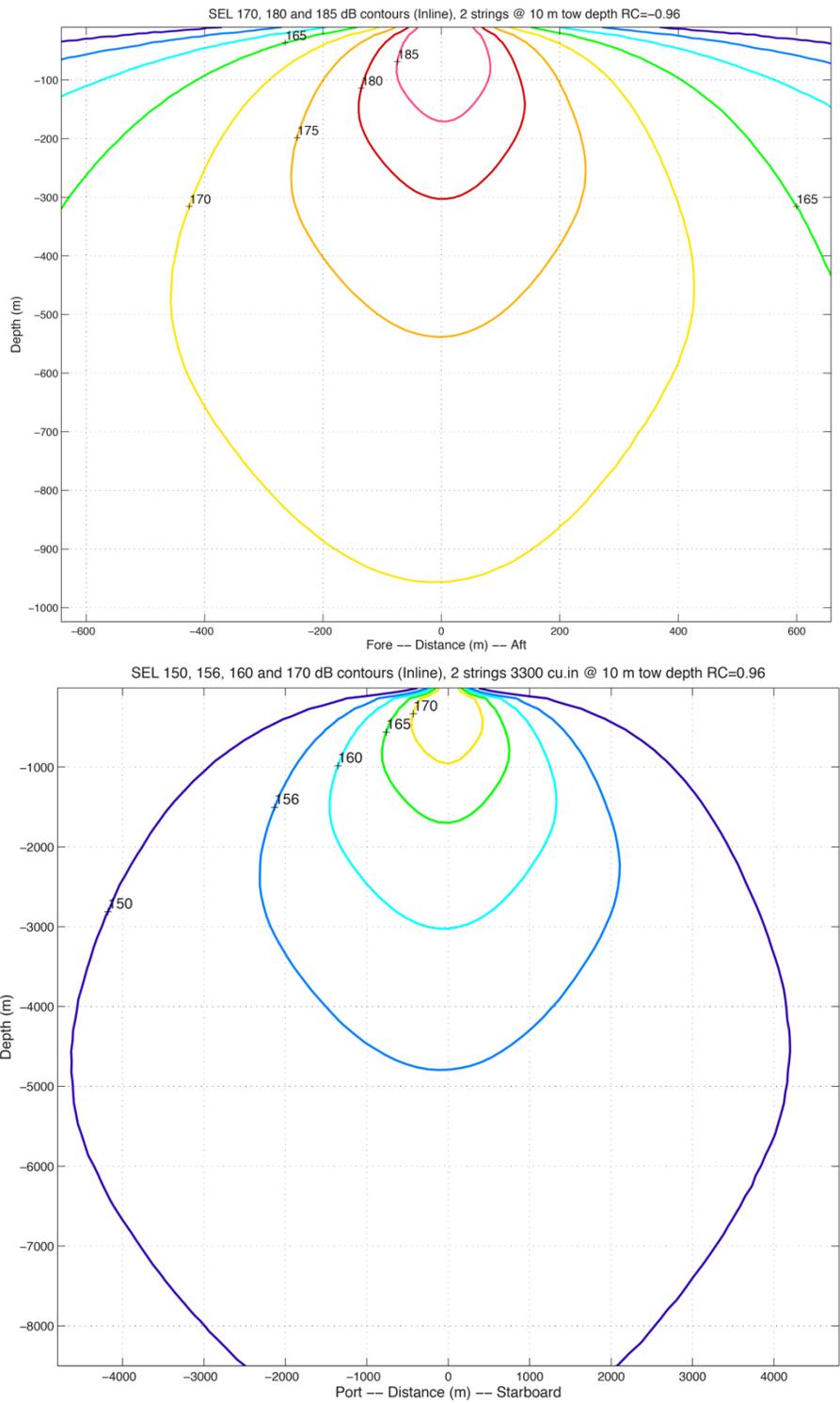


FIGURE A-2. Modeled deep-water received sound exposure levels (SELs) from the 18-airgun array at a 10-m tow depth planned for use during the 3-D survey in the Northeast Pacific Ocean. Received rms levels (SPLs) are expected to be ~10 dB higher. For example, the radius to the 150-dB SEL isopleth is a proxy for the 160-dB rms isopleth. The upper plot is a zoomed-in version of the lower plot.

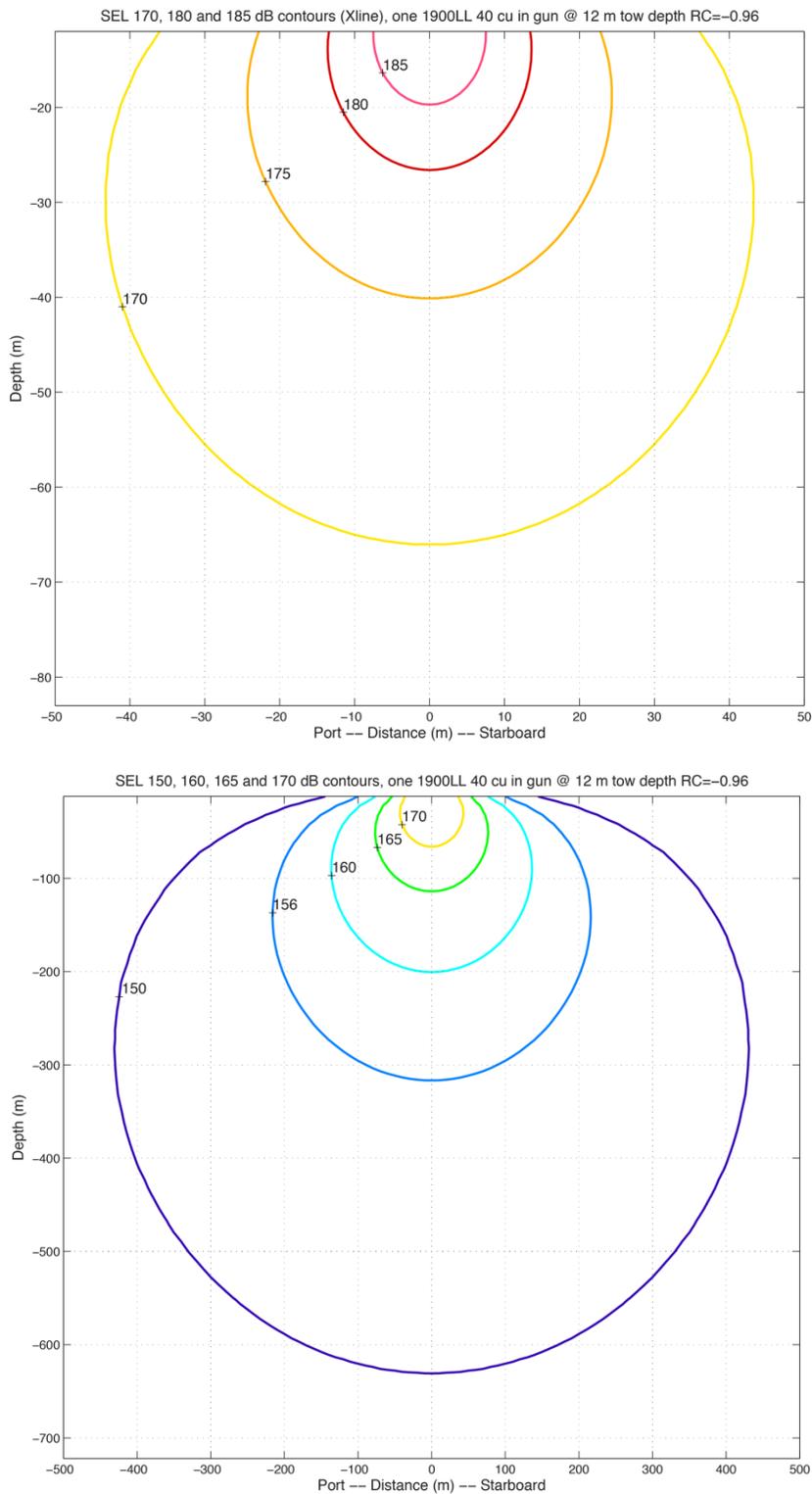


FIGURE A-3. Modeled deep-water received SELs from a single 40-in³ airgun (towed at a 12-m depth), which is planned for use as a mitigation airgun during the proposed surveys in the Northeast Pacific Ocean. Received rms levels (SPLs) are expected to be ~10 dB higher. For example, the radius to the 150-dB SEL isopleth is a proxy for the 160-dB rms isopleth. The upper plot is a zoomed-in version of the lower plot.

Table A-1 shows the distances at which the 160-dB re $1\mu\text{Pa}_{\text{rms}}$ sound levels are expected to be received for the 18- and 36-airgun array and the single (mitigation) airgun. The 160-dB level is the behavioral disturbance criterion (Level B) that is used by NMFS to estimate anticipated takes for marine mammals. A recent retrospective analysis of acoustic propagation of R/V *Langseth* sources in a coastal/shelf environment from the Cascadia Margin off Washington suggests that predicted (modeled) radii (using an approach similar to that used here) for R/V *Langseth* sources were 2–3 times larger than measured in shallow water, so in fact, as expected, were very conservative (Crone et al. 2014). Similarly, data collected by Crone et al. (2017) during a survey off New Jersey in 2014 and 2015 confirmed that *in situ* measurements and estimates of the 160- and 180-dB distances collected by R/V *Langseth* hydrophone streamer were 2–3 times smaller than the predicted operational mitigation radii. In fact, five separate comparisons conducted of the L-DEO model with *in situ* received levels² have confirmed that the L-DEO model generated conservative EZs, resulting in significantly larger EZs than required by National Oceanic and Atmospheric Administration’s (NOAA) National Marine Fisheries Service (NMFS).

In July 2016, NMFS released new technical guidance for assessing the effects of anthropogenic sound on marine mammal hearing (NMFS 2016, 2018). The new guidance established new thresholds for permanent threshold shift (PTS) onset or Level A Harassment (injury), for marine mammal species. The new noise exposure criteria for marine mammals account for the newly-available scientific data on temporary threshold shifts (TTS), the expected offset between TTS and PTS thresholds, differences in the acoustic frequencies to which different marine mammal groups are sensitive, and other relevant factors, as summarized by Finneran (2016). For impulsive sources, onset of PTS was assumed to be 15 dB or 6 dB higher when considering SEL_{cum} and SPL_{flat} , respectively. The new guidance incorporates marine mammal auditory weighting functions (Fig. A-4) and dual metrics of cumulative sound exposure level (SEL_{cum} over 24 hours) and peak sound pressure levels (SPL_{flat}). Different thresholds are provided for the various hearing groups, including low-frequency (LF) cetaceans (e.g., baleen whales), mid-frequency (MF) cetaceans (e.g., most delphinids), high-frequency (HF) cetaceans (e.g., porpoise and *Kogia* spp.), phocids underwater (PW), and otariids underwater (OW). As required by NMFS (2016, 2018), the largest distance of the dual criteria (SEL_{cum} or Peak SPL_{flat}) was used to calculate takes and Level A threshold distances. The new guidance did not alter the current threshold, 160 dB re $1\mu\text{Pa}_{\text{rms}}$, for Level B harassment (behavior).

The SEL_{cum} for R/V *Langseth* array is derived from calculating the modified farfield signature. The farfield signature is often used as a theoretical representation of the source level. To compute the farfield signature, the source level is estimated at a large distance directly below the array (e.g., 9 km), and this level is back projected mathematically to a notional distance of 1 m from the array’s geometrical center. However, it has been recognized that the source level from the theoretical farfield signature is never physically achieved at the source when the source is an array of multiple airguns separated in space (Tolstoy et al. 2009). Near the source (at short ranges, distances <1 km), the pulses of sound pressure from each individual airgun in the source array do not stack constructively as they do for the theoretical farfield signature. The pulses from the different airguns spread out in time such that the source levels observed or modeled are the result of the summation of pulses from a few airguns, not the full array

² L-DEO surveys off the Yucatán Peninsula in 2004 (Barton et al. 2006; Diebold et al. 2006), in the Gulf of Mexico in 2008 (Tolstoy et al. 2009; Diebold et al. 2010), off Washington and Oregon in 2012 (Crone et al. 2014), and off New Jersey in 2014 and 2015 (Crone et al. 2017).

TABLE A-1. Level B. Predicted distances to which sound levels ≥ 160 -dB re $1 \mu\text{Pa}_{\text{rms}}$ could be received during the proposed surveys in the Northeast Pacific Ocean. The 160-dB criterion applies to all hearing groups of marine mammals.

Source and Volume	Maximum Tow Depth (m)	Water Depth (m)	Predicted distances (in m) to the 160-dB Received Sound Level ¹
Single Bolt airgun, 40 in ³	12	>1000 m	431
2 strings, 18 airguns, 3300 in ³	10	>1000 m	3758
4 strings, 36 airguns, 6600 in ³	12	>1000 m	6733

¹ Distance is based on L-DEO model results.

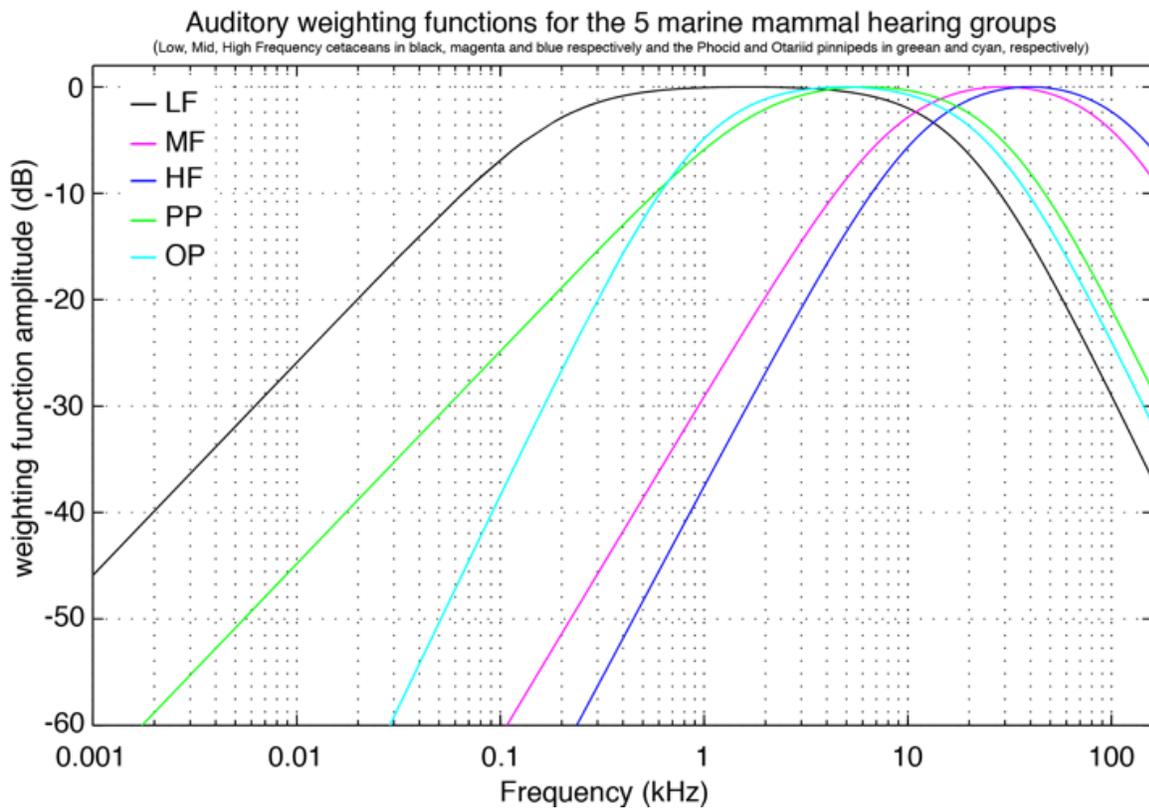


FIGURE A-4. Auditory weighting functions for five marine mammal hearing groups from the NMFS Technical Guidance Spreadsheet.

(Tolstoy et al. 2009). At larger distances, away from the source array center, sound pressure of all the airguns in the array stack coherently, but not within one time sample, resulting in smaller source levels (a few dB) than the source level derived from the farfield signature. Because the farfield signature does not take into account the large array effect near the source and is calculated as a point source, the farfield signature is not an appropriate measure of the sound source level for large arrays.

To estimate SEL_{cum} and Peak SPL, we used the acoustic modeling developed at L-DEO (same as used for Level B takes) with a small grid step in both the inline and depth directions. The propagation modeling takes into account all airgun interactions at short distances from the source including interactions between subarrays which we do using the NUCLEUS software to estimate the notional signature and the MATLAB software to calculate the pressure signal at each mesh point of a grid.

PTS onset acoustic thresholds estimated in the NMFS User Spreadsheet rely on overriding the default values and calculating individual adjustment factors (dB) based on the modified farfield and by using the difference between levels with and without weighting functions for each of the five categories of hearing groups. The new adjustment factors in the spreadsheet allow for the calculation of SEL_{cum} isopleths in the spreadsheet and account for the accumulation (Safe Distance Methodology) using the source characteristics (source velocity and duty) after Sivle et al. (2014). A source velocity of 2.16067 m/s and a 1/Repetition rate of 17.3557 s were used as inputs to the NMFS User Spreadsheet for calculating the distances to the SEL_{cum} PTS thresholds (Level A) for the 36-airgun array; a source velocity of 2.315 m/s and a 1/Repetition rate of 16.1987 s were used for the 18-airgun array and the 40-in³ airgun.

For the LF cetaceans, we estimated a new adjustment value by computing the distance from the geometrical center of the source to where the 183 dB SEL_{cum} isopleth is the largest. We first ran the modeling for a single shot without applying any weighting function; we then ran the modeling for a single shot with the LF cetacean weighting function applied to the full spectrum. The difference between these values provides an adjustment factor and assumes a propagation of $20\log_{10}(\text{Radial distance})$.

However, for MF and HF cetaceans, and OW and PW pinnipeds, the modeling for a single shot with the weighted function applied leads to 0-m isopleths; the adjustment factors thus cannot be derived the same way as for LF cetaceans. Hence, for MF and HF cetaceans, and OW and PW pinnipeds, the difference between weighted and unweighted spectral source levels at each frequency up to 3 kHz was integrated to actually calculate these adjustment factors in dB. These calculations also account for the accumulation (Safe Distance Methodology) using the source characteristics (duty cycle and speed) after Sivle et al. (2014).

For the 36-airgun array, the results for single shot SEL source level modeling are shown in Table A-2; an adjustment factor of -12.91 dB was calculated for low-frequency cetaceans. Figure A-5 shows the impact of weighting functions by hearing group on the spectral density of the airgun array farfield signature. The weighting function calculations, thresholds for SEL_{cum} , and the distances to the PTS thresholds for the 36-airgun array are shown in Table A-3. Figures A-6–A-8 show the modeled received sound levels for single shot SEL without applying auditory weighting functions for various hearing groups. Figure A-9 shows the modeled received sound levels for single shot SEL with weighting for LF cetaceans.

The thresholds for Peak SPL_{flat} for the 36-airgun array, as well as the distances to the PTS thresholds, are shown in Table A-4. Figures A-10–A-12 show the modeled received sound levels to the Peak SPL_{flat} thresholds, for a single shot.

TABLE A-2. Results for single SEL source level modeling for the 36-airgun array with and without applying weighting functions to the five hearing groups. The modified farfield signature is estimated using the distance from the source array geometrical center to where the SEL_{cum} threshold is the largest. A propagation of $20 \log_{10}$ (Radial distance) is used to estimate the modified farfield SEL.

SEL _{cum} Threshold	183	185	155	185	203
Radial Distance (m) (no weighting function)	315.569	246.468	8033.2	246.468	28.441
Modified Farfield SEL	232.982	232.835	233.098	232.835	232.079
Radial Distance (m) (with weighting function)	71.375	N.A.	N.A.	N.A.	N.A.
Adjustment (dB)	-12.91	N.A.	N.A.	N.A.	N.A.

* Propagation of $20 \log R$. N.A. means not applicable or not available.

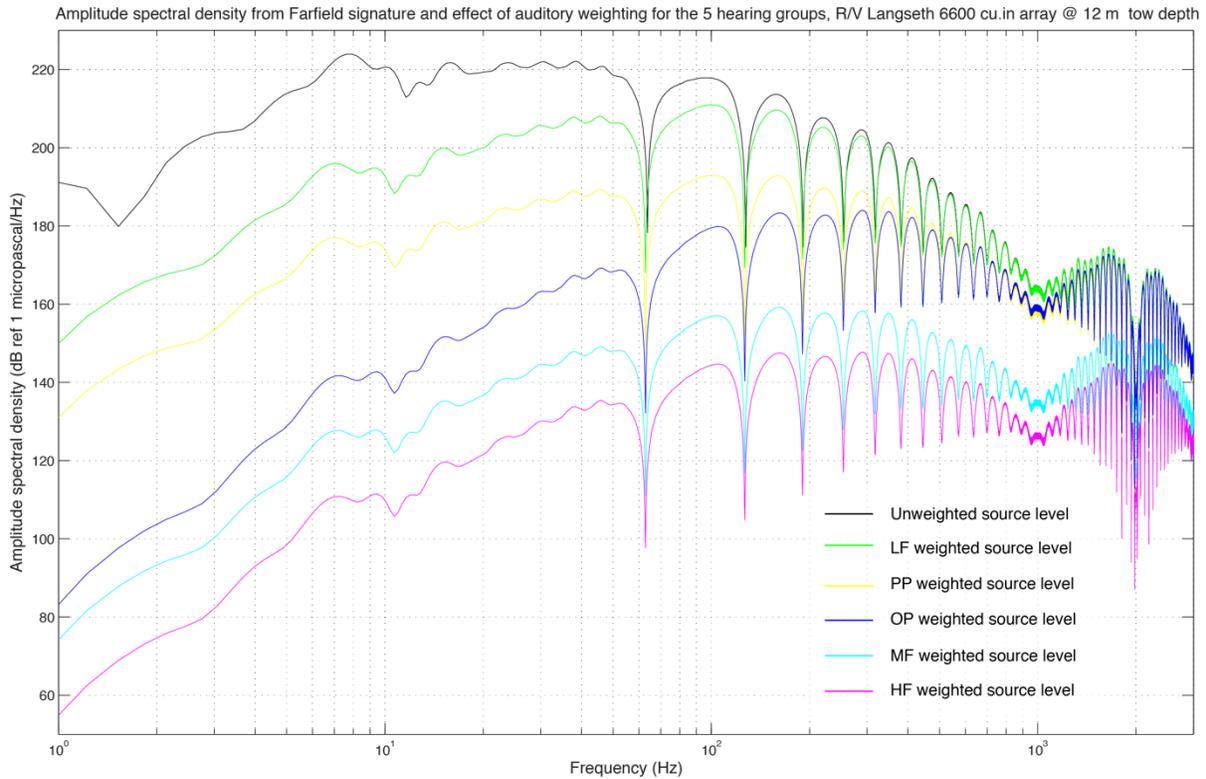


FIGURE A-5. Modeled amplitude spectral density of the 36-airgun array farfield signature. Amplitude spectral density before (black) and after (colors) applying the auditory weighting functions for LF, MF, and HF cetaceans, Phocid Pinnipeds (PP), and Otariid Pinnipeds (OP). Modeled spectral levels are used to calculate the difference between the unweighted and weighted source level at each frequency and to derive the adjustment factors for the hearing groups as inputs into the NMFS User Spreadsheet.

TABLE A-3. Results for single shot SEL source level modeling for the 36-airgun array with weighting function calculations for the SEL_{cum} criteria, as well as resulting isopleths to thresholds for various hearing groups.

STEP 1: GENERAL PROJECT INFORMATION						
PROJECT TITLE	R/V Langseth (PI: Arnulf)					
PROJECT/SOURCE INFORMATION	source : 4 string 36 element 6600 cu.in of the R/V Langseth at a 12m towed depth. Shot interval of 37.5 m. Source velocity of 4.2 knots					
Please include any assumptions						
PROJECT CONTACT						
STEP 2: WEIGHTING FACTOR ADJUSTMENT		Specify if relying on source-specific WFA, alternative weighting/dB adjustment, or if using default value				
Weighting Factor Adjustment (kHz) ^Y	NA	Override WFA: Using LDEO modeling				
^Y Broadband: 95% frequency contour percentile (kHz) OR Narrowband: frequency (kHz); For appropriate default WFA: See INTRODUCTION tab						
		† If a user relies on alternative weighting/dB adjustment rather than relying upon the WFA (source-specific or default), they may override the Adjustment (dB) (row 62), and enter the new value directly. However, they must provide additional support and documentation supporting this modification.				
* BROADBAND Sources: Cannot use WFA higher than maximum applicable frequency (See GRAY tab for more information on WFA applicable frequencies)						
STEP 3: SOURCE-SPECIFIC INFORMATION						
NOTE: Choose either F1 OR F2 method to calculate isopleths (not required to fill in sage boxes for both)						NOTE: LDEO modeling relies on Method F2
F2: ALTERNATIVE METHOD[†] TO CALCULATE PK and SEL_{cum} (SINGLE STRIKE/SHOT/PULSE EQUIVALENT)						
SEL _{cum}						
Source Velocity (meters/second)	2.16067	4.2 knots				
1/Repetition rate [^] (seconds)	17.3557	37.5 m /2.16067				
†Methodology assumes propagation of 20 log R; Activity duration (time) independent						
‡Time between onset of successive pulses.						
	Modified farfield SEL	232.9819	232.8352	233.0978	232.8352	232.079
	Source Factor	1.14485E+22	1.10682E+22	1.17581E+22	1.10682E+22	9.29946E+21
RESULTANT ISOPLETHS*						
*Impulsive sounds have dual metric thresholds (SEL _{cum} & PK). Metric producing largest isopleth should be used.						
	Hearing Group	Low-Frequency Cetaceans	Mid-Frequency Cetaceans	High-Frequency Cetaceans	Phocid Pinnipeds	Otariid Pinnipeds
	SEL _{cum} Threshold	183	185	155	185	203
	PTS SEL _{cum} Isopleth to threshold (meters)	426.9	0	1.3	13.9	0
WEIGHTING FUNCTION CALCULATIONS						
	Weighting Function Parameters	Low-Frequency Cetaceans	Mid-Frequency Cetaceans	High-Frequency Cetaceans	Phocid Pinnipeds	Otariid Pinnipeds
	a	1	1.6	1.8	1	2
	b	2	2	2	2	2
	f ₁	0.2	8.8	12	1.9	0.94
	f ₂	19	110	140	30	25
	C	0.13	1.2	1.36	0.75	0.64
	Adjustment (dB) [†]	-12.91	-56.70	-66.07	-25.65	-32.62
 OVERRIDE Using LDEO Modeling						

†For LF cetaceans, the adjustment factor (dB) is derived by estimating the radial distance of the 183-dB isopleth without applying the weighting function and a second time with applying the weighting function. Adjustment was derived using a propagation of $20 \cdot \log_{10}$ (Radial distance) and the modified farfield signature. For MF and HF cetaceans and pinnipeds, the difference between weighted–unweighted spectral source levels at each frequency was integrated to calculate adjustment factors (see spectrum levels in Figure A-5).

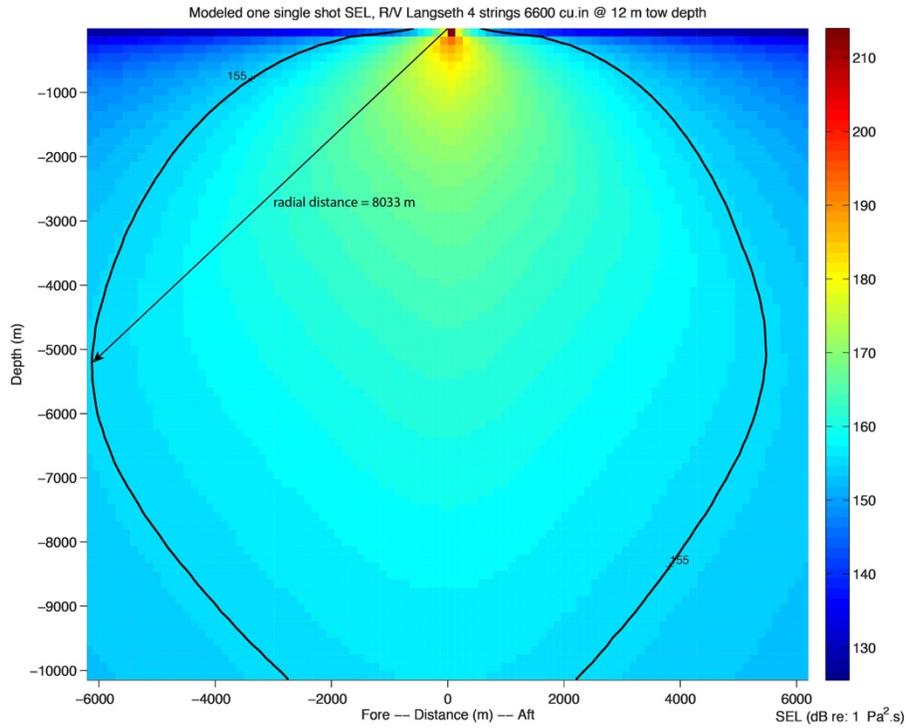


FIGURE A-6. Modeled received sound levels (SELs) in deep water from the 36-airgun array. The plot provides the radial distance from the geometrical center of the source array to the 155-dB SEL isopleth (8033 m). Radial distance allows us to determine the modified farfield SEL using a propagation of $20\log_{10}(\text{radial distance})$.

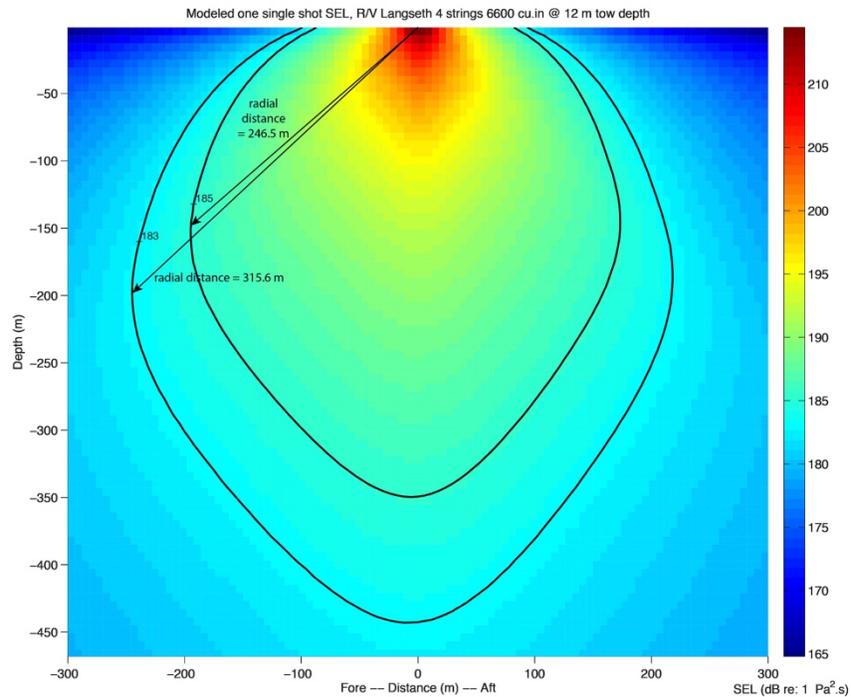


FIGURE A-7. Modeled received sound levels (SELs) in deep water from the 36-airgun array. The plot provides the radial distance from the geometrical center of the source array to the 183–185-dB SEL isopleths (315.6 and 246.5 m, respectively).

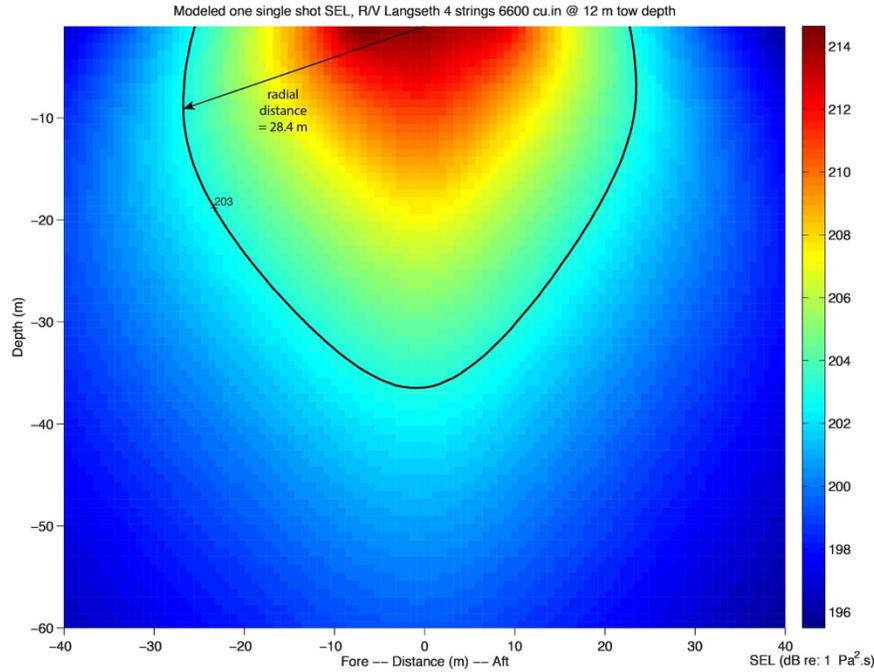


FIGURE A-8. Modeled received sound levels (SELs) in deep water from the 36-airgun array. The plot provides the radial distance from the geometrical center of the source array to the 203-dB SEL isopleth (28.4 m).

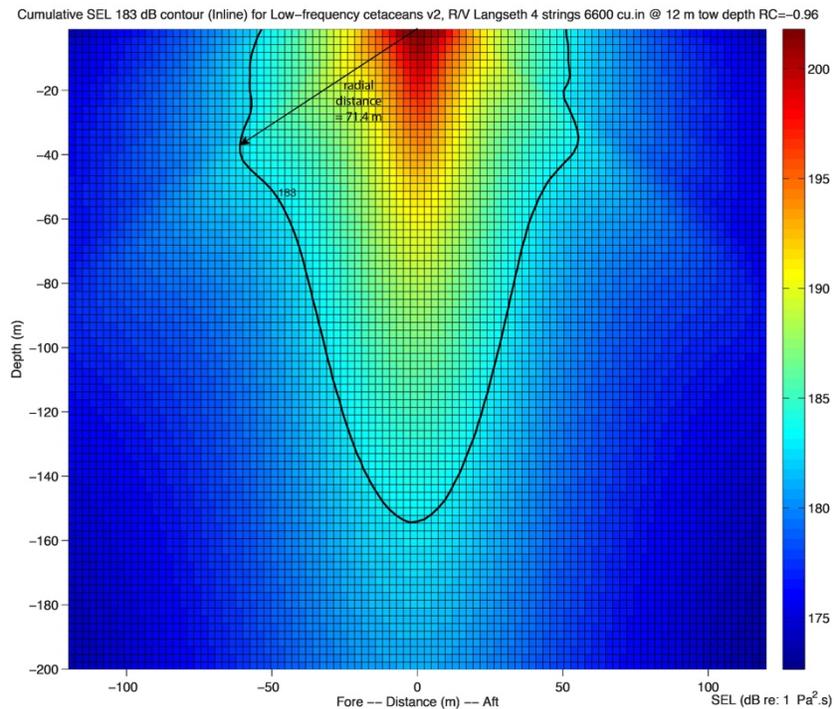


FIGURE A-9. Modeled received sound exposure levels (SELs) from the 36-airgun array at a 12-m tow depth, after applying the auditory weighting function for the LF cetaceans hearing group following the NMFS Technical Guidance. The plot provides the radial distance to the 183-dB SEL_{cum} isopleth for one shot. The difference in radial distances between Fig. A-7 and this figure (71.4 m) allows us to estimate the adjustment in dB.

TABLE A-4. NMFS Level A acoustic thresholds (Peak SPL_{flat}) for impulsive sources for marine mammals and predicted distances to Level A thresholds for various marine mammal hearing groups that could be received from the 36-airgun array during the proposed 2-D survey in the Northeast Pacific Ocean.

Hearing Group	Low-Frequency Cetaceans	Mid-Frequency Cetaceans	High-Frequency Cetaceans	Phocid Pinnipeds	Otariid Pinnipeds
Peak Threshold	219	230	202	218	232
PTS Peak Isoleth (Radius) to Threshold (m)	38.9	13.6	268.3	43.7	10.6

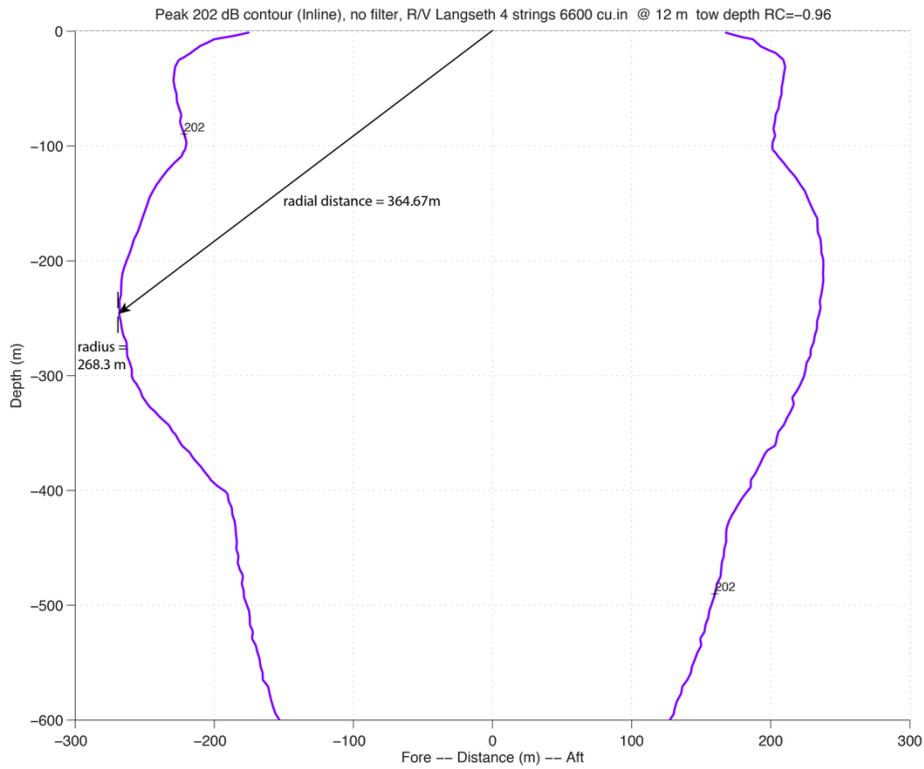


FIGURE A-10. Modeled deep-water received Peak SPL from the 36-airgun array at a 12-m tow depth. The plot provides the distance to the 202-dB Peak isopleths.

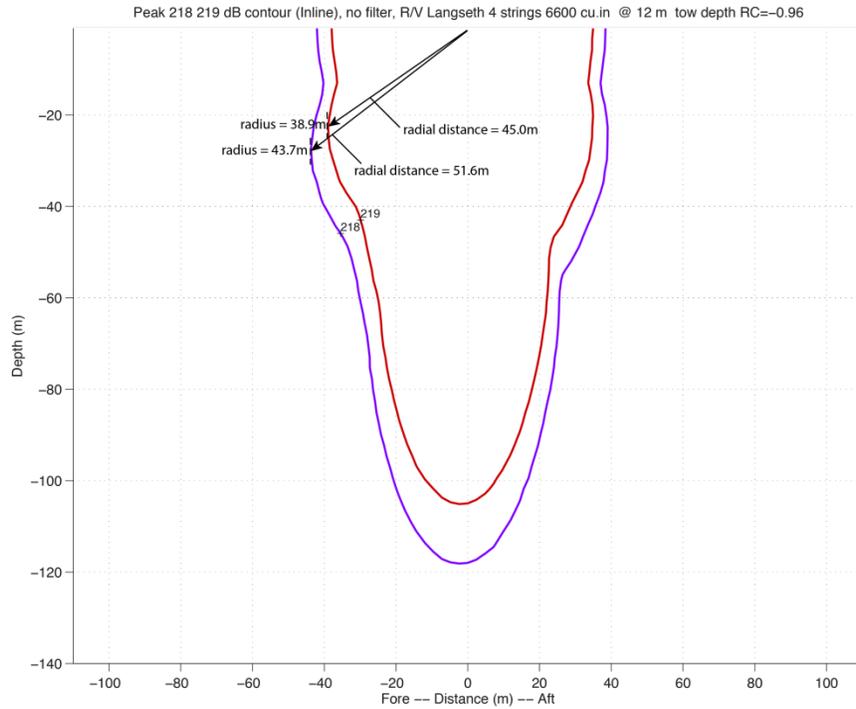


FIGURE A-11. Modeled deep-water received Peak SPL from the 36-airgun array at a 12-m tow depth. The plot provides the distances to the 218- and 219-dB Peak isopleths.

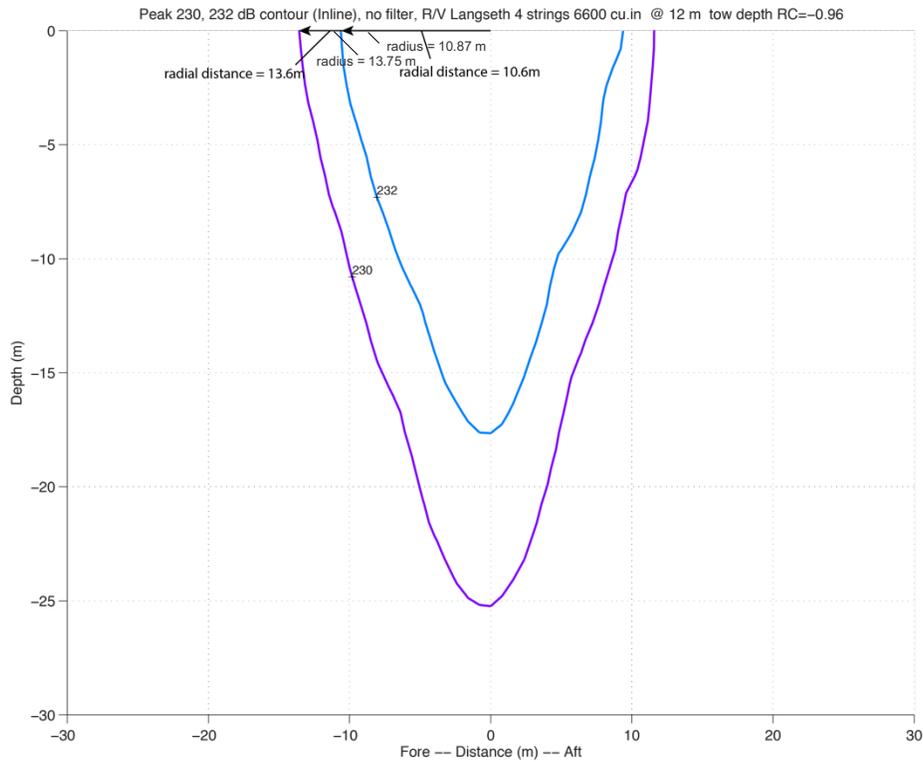


FIGURE A-12. Modeled deep-water received Peak SPL from the 36-airgun array at a 12-m tow depth. The plot provides the distances to the 230- and 232-dB Peak isopleths.

For the 18-airgun array, the results for single shot SEL source level modeling are shown in Table A-5; an adjustment factor of -13.82 dB was calculated for low-frequency cetaceans. The weighting function calculations, thresholds for SEL_{cum} , and the distances to the PTS thresholds for the 18-airgun array are shown in Table A-6. Figure A-13 shows the impact of weighting functions by hearing group on the spectral density of the airgun array farfield signature. Figures A-14–A-15 show the modeled received sound levels for single shot SEL without applying auditory weighting functions for various hearing groups. Figure A-16 shows the modeled received sound levels for single shot SEL with weighting for LF cetaceans.

The thresholds for Peak SPL_{flat} for the 18-airgun array, as well as the distances to the PTS thresholds, are shown in Table A-7. Figures A-17–A-19 show the modeled received sound levels to the Peak SPL_{flat} thresholds, for a single shot. A summary of the Level A threshold distances for the 18- and 36-airgun arrays are shown in Table A-8.

For the single 40 in³ mitigation airgun, the results for single shot SEL source level modeling are shown in Table A-9. Figure A-20 shows the impact of weighting functions by hearing group on the spectral density of the airgun farfield signature. The weighting function calculations, thresholds for SEL_{cum} , and the distances to the PTS thresholds for the 40 in³ airgun are shown in Table A-10. Figures A-21–A-22 show the modeled received sound levels for single shot SEL without applying auditory weighting functions for various hearing groups. Figure A-23 shows the modeled received sound levels for single shot SEL with weighting for LF cetaceans. The thresholds for Peak SPL_{flat} for the 40 in³ airgun, as well as the distances to the PTS thresholds, are shown in Table A-11. Figures A-24–A-25 show the modeled received sound levels to the Peak SPL_{flat} thresholds, for a single shot.

Table A-12 shows the distances at which the 175- and 195-dB re 1 μ Pa_{rms} sound levels are expected to be received for the 36-airgun array, and a single airgun, based on L-DEO modeling. The 195-dB distance would be used as the EZ for sea turtles, as required by NMFS. The 175-dB level is used by NMFS, based on data from the USN (2017), to determine behavioral disturbance for turtles.

TABLE A-5. Results for single SEL source level modeling for the 18-airgun array with and without applying weighting functions to the five hearing groups. The modified farfield signature is estimated using the distance from the source array geometrical center to where the SEL_{cum} threshold is the largest. A propagation of $20 \log_{10}$ (Radial distance) is used to estimate the modified farfield SEL.

SEL_{cum} Threshold	183	185	155	185	203
Radial Distance (m) (no weighting function)	147.580	116.495	3826.4	116.495	15.969
Modified Farfield SEL	226.381	226.326	226.656	226.326	227.066
Radial Distance (m) (with weighting function)	29.897	N/A	N/A	N/A	N/A
Adjustment (dB)	-13.82	N/A	N/A	N/A	N/A

* Propagation of $20 \log R$. N.A. means not applicable or not available.

TABLE A-6. Results for single shot SEL source level modeling for the 18-airgun array with weighting function calculations for the SEL_{cum} criteria, as well as resulting isopleths to thresholds for various hearing groups.

STEP 1: GENERAL PROJECT INFORMATION						
PROJECT TITLE	R/V Langseth (PI: Arnulf)					
PROJECT/SOURCE INFORMATION	source: 2 string 18 element 3300 cu.in of the R/V Langseth at a 10-m tow depth. Shot interval of 37.5 m. Source velocity of 4.5 knots.					
PROJECT CONTACT						
STEP 2: WEIGHTING FACTOR ADJUSTMENT						
Specify if relying on source-specific WFA, alternative weighting/dB adjustment, or if using default value						
Weighting Factor Adjustment (kHz) [‡]	NA					
Override WFA: Using LDEO modeling						
[‡] Broadband: 95% frequency contour percentile (kHz) OR Narrowband: frequency (kHz); For appropriate default WFA: See INTRODUCTION tab [†] If a user relies on alternative weighting/dB adjustment rather than relying upon the WFA (source-specific or default), they may override the Adjustment (dB) (row 62), and enter the new value directly. However, they must provide additional support and documentation supporting this modification.						
STEP 3: SOURCE-SPECIFIC INFORMATION						
NOTE: Choose either F1 OR F2 method to calculate isopleths (not required to fill in sage boxes for both)						
NOTE: LDEO modeling relies on Method F2						
F2: ALTERNATIVE METHOD¹ TO CALCULATE PK and SEL_{cum} (SINGLE STRIKE/SHOT/PULSE EQUIVALENT)						
SEL _{cum}						
Source Velocity (meters/second)	2	(4.5 knots)				
1/Repetition rate ² (seconds)	16	37.5/2.315				
¹ Methodology assumes propagation of 20 log R; Activity duration (time) independent ² Time between onset of successive pulses.						
	Modified farfield SEL	226	226	227	226	227
	Source Factor	2.68E+21	2.65E+21	2.86E+21	2.65E+21	3.14E+21
RESULTANT ISOPLETHS*						
*Impulsive sounds have dual metric thresholds (SEL _{cum} & PK). Metric producing largest isopleth should be used.						
Hearing Group	Low-Frequency Cetaceans	Mid-Frequency Cetaceans	High-Frequency Cetaceans	Phocid Pinnipeds	Otariid Pinnipeds	
SEL _{cum} Threshold	183	185	155	185	203	
PTS SEL _{cum} Isopleth to threshold (meters)	75.6	0	0.3	2.9	0	
WEIGHTING FUNCTION CALCULATIONS						
	Weighting Function Parameters	Low-Frequency Cetaceans	Mid-Frequency Cetaceans	High-Frequency Cetaceans	Phocid Pinnipeds	Otariid Pinnipeds
	a	1	2	2	1	2
	b	2	2	2	2	2
	f ₁	0	9	12	2	1
	f ₂	19	110	140	30	25
	C	0	1	1	1	1
	Adjustment (dB) [†]	-14	-57	-66	-26	-33
 OVERRIDE Using LDEO Modeling						

[†]For LF cetaceans, the adjustment factor (dB) is derived by estimating the radial distance of the 183-dB isopleth without applying the weighting function and a second time with applying the weighting function. Adjustment was derived using a propagation of 20*log₁₀ (Radial distance) and the modified farfield signature. For MF and HF cetaceans and pinnipeds, the difference between weighted–unweighted spectral source levels at each frequency was integrated to calculate adjustment factors (see spectrum levels in Figure A-13).

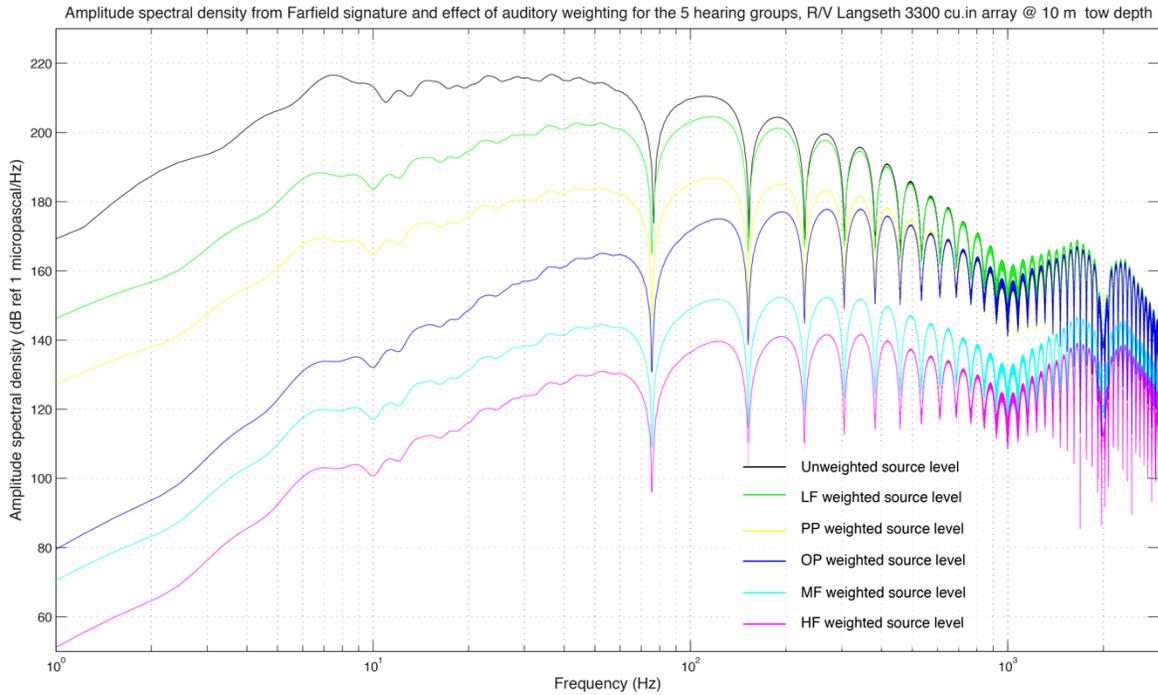


FIGURE A-13. Modeled amplitude spectral density of the 18-airgun array farfield signature. Amplitude spectral density before (black) and after (colors) applying the auditory weighting functions for LF, MF, and HF cetaceans, Phocid Pinnipeds (PP), and Otariid Pinnipeds (OP). Modeled spectral levels are used to calculate the difference between the unweighted and weighted source level at each frequency.

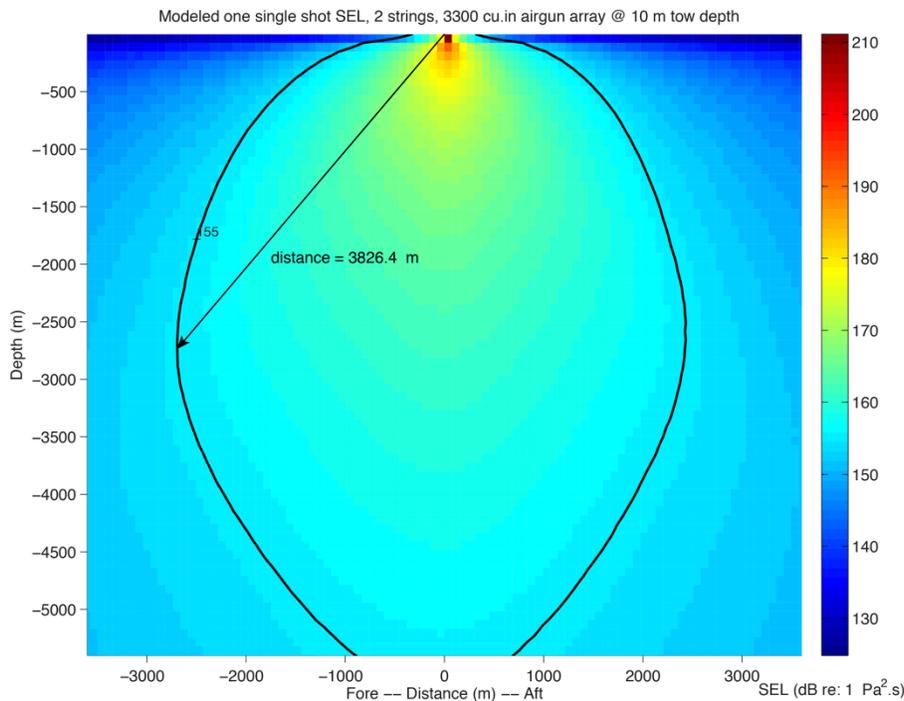


FIGURE A-14. Modeled received sound levels (SELs) in deep water from the 18-airgun array. The plot provides the radial distance from the geometrical center of the source array to the 155-dB SEL isopleth (3826 m). Radial distance allows us to determine the modified farfield SEL using a propagation of $20\log_{10}(\text{radial distance})$.

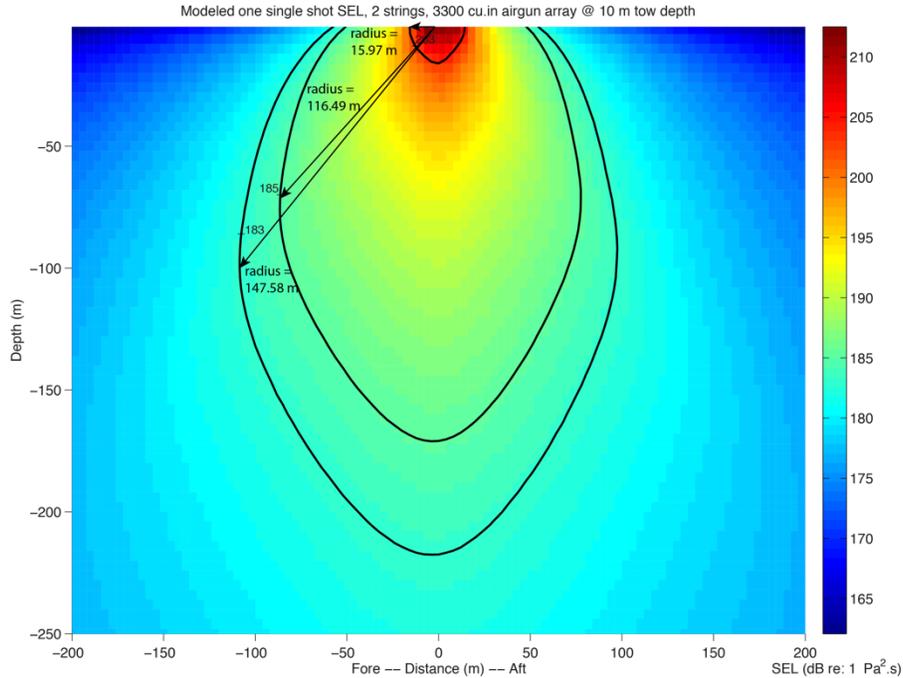


FIGURE A-15. Modeled received sound levels (SELs) in deep water from the 18-airgun array. The plot provides the radial distance from the geometrical center of the source array to the 183-, 185-, and 203-dB SEL isopleths.

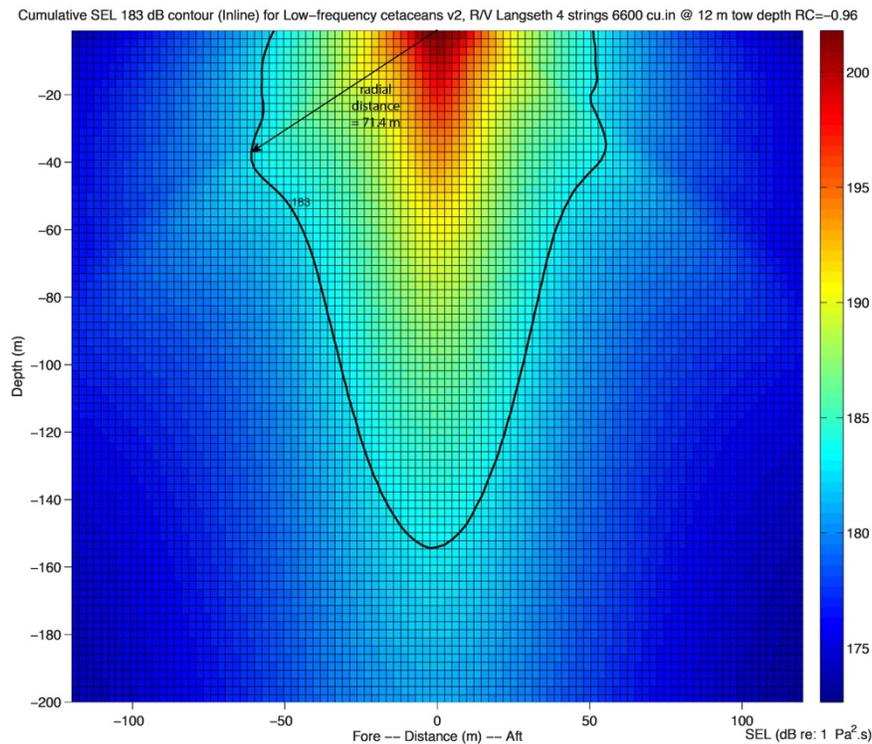


FIGURE A-16. Modeled received sound exposure levels (SELs) from the 18-airgun array at a 10-m tow depth, after applying the auditory weighting function for the LF cetaceans hearing group following the NMFS Technical Guidance. The plot provides the radial distance to the 183-dB SEL_{cum} isopleth for one shot. The difference in radial distances between Fig. A-15 (11.3 m) and this figure (4.96 m) allows us to estimate the adjustment in dB.

TABLE A-7. NMFS Level A acoustic thresholds (Peak SPL_{flat}) for impulsive sources for marine mammals and predicted distances to Level A thresholds for various marine mammal hearing groups that could be received from the 18-airgun array during the proposed 3-D survey in the Northeast Pacific Ocean.

Hearing Group	Low-Frequency Cetaceans	Mid-Frequency Cetaceans	High-Frequency Cetaceans	Phocid Pinnipeds	Otariid Pinnipeds
Peak Threshold	219	230	202	218	232
PTS Peak Isoleth (Radius) to Threshold (m)	23.15	11.8	118.7	25.13	9.91

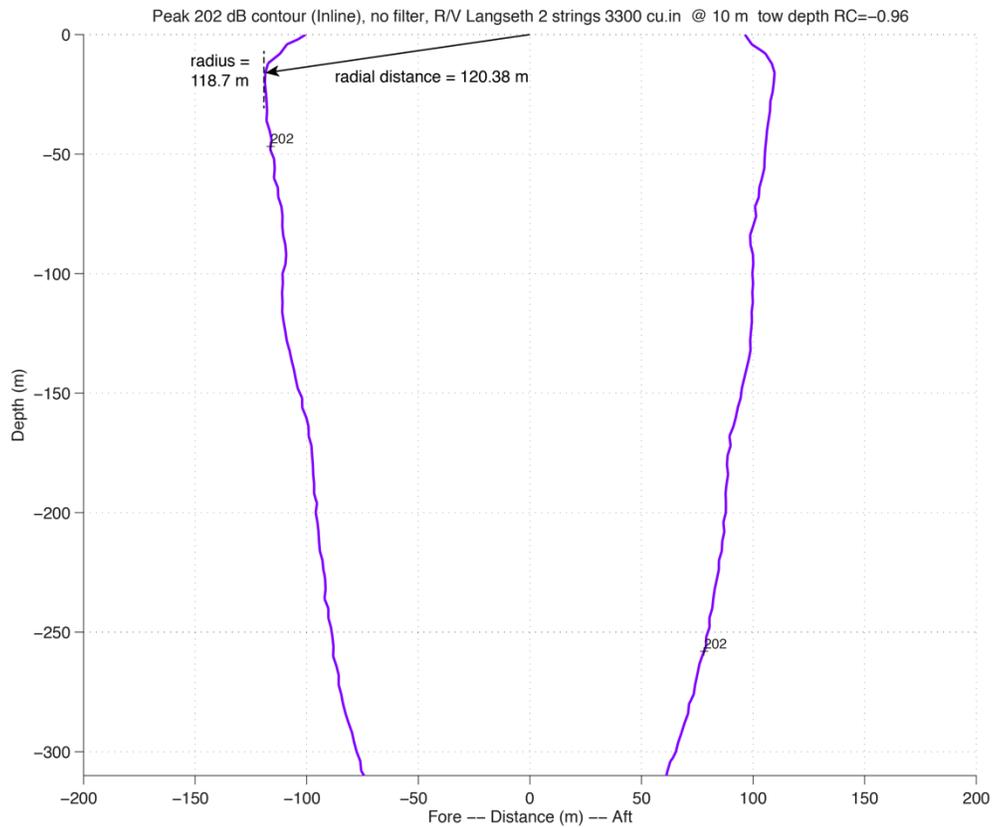


FIGURE A-17. Modeled deep-water received Peak SPL from the 18-airgun array at a 10-m tow depth. The plot provides the distance to the 202-dB Peak isopleths.

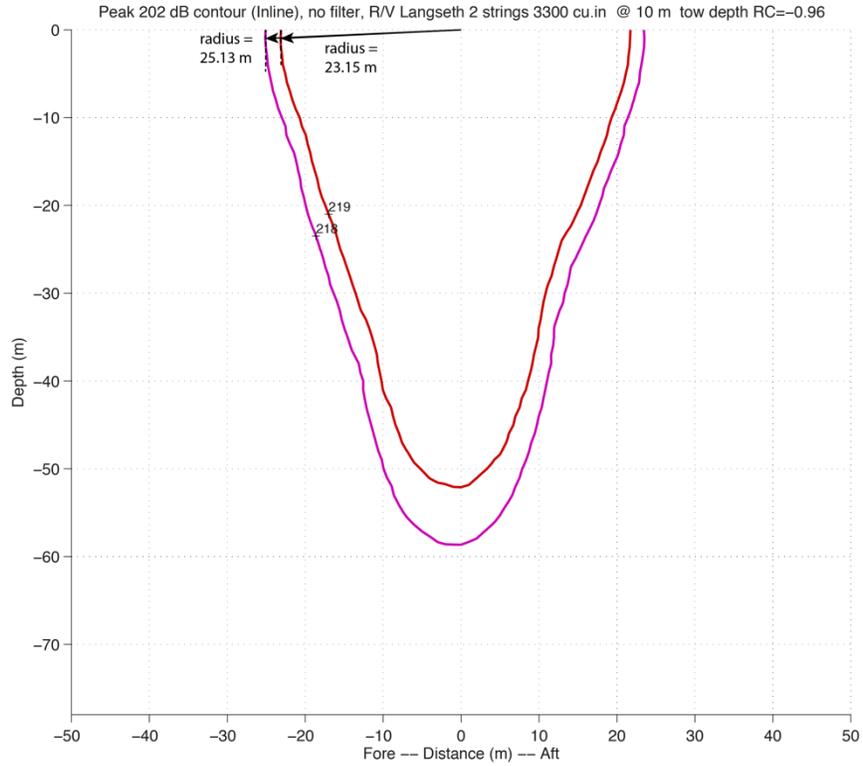


FIGURE A-18. Modeled deep-water received Peak SPL from the 18-airgun array at a 10-m tow depth. The plot provides the distances to the 218- and 219-dB Peak isopleths.

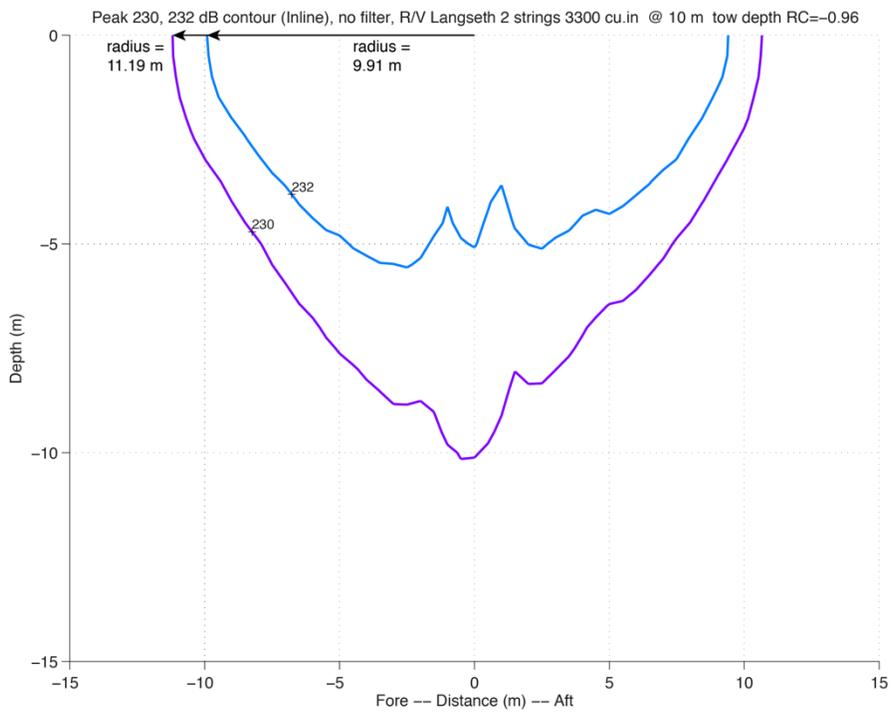


FIGURE A-19. Modeled deep-water received Peak SPL from the 18-airgun array at a 10-m tow depth. The plot provides the distances to the 230- and 232-dB Peak isopleths.

TABLE A-8. Level A threshold distances for different marine mammal hearing groups. As required by NMFS (2016, 2018), the largest distance (in bold) of the dual criteria (SEL_{cum} or Peak SPL_{flat}) was used to calculate takes and Level A threshold distances.

Level A Threshold Distances (m) for Various Hearing Groups					
	Low-Frequency Cetaceans	Mid-Frequency Cetaceans	High-Frequency Cetaceans	Phocid Pinnipeds	Otariid Pinnipeds
18-airgun array; 3300 in ³					
PTS SEL_{cum}	75.6	0	0.3	2.9	0
PTS Peak	23.2	11.2	118.7	25.1	9.9
36-airgun array; 6600 in ³					
PTS SEL_{cum}	426.9	0	1.3	13.9	0
PTS Peak	38.9	13.6	268.3	43.7	10.6

TABLE A-9. Results for single shot SEL source level modeling for the 40-in³ airgun with and without applying weighting function to the various hearing groups. The modified farfield signature is estimated using the distance from the source array geometrical center to where the SEL_{cum} threshold is the largest. A propagation of $20 \log_{10}$ (Radial distance) is used to estimate the modified farfield SEL.

SEL_{cum} Threshold	183	185	155	185	203
Distance (m) (no weighting function)	9.9893	7.8477	294.0371	7.8477	0.9278
Modified Farfield SEL*	202.9907	202.8948	204.3680	202.8948	202.3491
Distance (m) (with weighting function)	2.3852	N.A.	N.A.	N.A.	N.A.
Adjustment (dB)	-12.44	N.A.	N.A.	N.A.	N.A.

*Propagation of $20 \log R$. N.A. means not applicable or not available.

TABLE A-10. Results for single shot SEL source level modeling for the single 40 in³ mitigation airgun with weighting function calculations for the SEL_{cum} criteria, as well as resulting isopleths to thresholds for various hearing groups.

STEP 1: GENERAL PROJECT INFORMATION						
PROJECT TITLE	R/V Langseth mitigation gun (Arnulf)					
PROJECT/SOURCE INFORMATION	one 40 cu.in 1900LL airgun @ a 12 m tow depth - speed of 4.5 knots and shot interval of 37.5 m					
Please include any assumptions						
PROJECT CONTACT						
STEP 2: WEIGHTING FACTOR ADJUSTMENT						
Specify if relying on source-specific WFA, alternative weighting/dB adjustment, or if using default value						
Weighting Factor Adjustment (kHz) [‡]	NA	Override WFA: Using LDEO modeling				
[‡] Broadband: 95% frequency contour percentile (kHz) OR Narrowband: frequency (kHz); For appropriate default WFA: See INTRODUCTION tab						
[†] If a user relies on alternative weighting/dB adjustment rather than relying upon the WFA (source-specific or default), they may override the Adjustment (dB) (row 62), and enter the new value directly. However, they must provide additional support and documentation supporting this modification.						
* BROADBAND Sources: Cannot use WFA higher than maximum applicable frequency (See GRAY tab for more information on WFA applicable frequencies)						
STEP 3: SOURCE-SPECIFIC INFORMATION						
NOTE: Choose either F1 OR F2 method to calculate isopleths (not required to fill in sage boxes for both)				NOTE: LDEO modeling relies on Method F2		
F2: ALTERNATIVE METHOD[†] TO CALCULATE PK and SEL_{cum} (SINGLE STRIKE/SHOT/PULSE EQUIVALENT)						
SEL _{cum}						
Source Velocity (meters/second)	2.315	4.5 knots				
1/Repetition rate [‡] (seconds)	16.1987	37.5/2.21211				
[‡] Methodology assumes propagation of 20 log R; Activity duration (time) independent						
[†] Time between onset of successive pulses.						
Modified farfield SEL	202.9907	202.8948	204.368	202.8948	202.3491	
Source Factor	1.22911E+19	1.20226E+19	1.6878E+19	1.20226E+19	1.0603E+19	
RESULTANT ISOPLETHS*						
*Impulsive sounds have dual metric thresholds (SEL _{cum} & PK). Metric producing largest isopleth should be used.						
Hearing Group	Low-Frequency Cetaceans	Mid-Frequency Cetaceans	High-Frequency Cetaceans	Phocid Pinnipeds	Otariid Pinnipeds	
SEL _{cum} Threshold	183	185	155	185	203	
PTS SEL _{cum} Isopleth to threshold (meters)	0.5	0.0	0.0	0.0	0.0	
WEIGHTING FUNCTION CALCULATIONS						
Weighting Function Parameters	Low-Frequency Cetaceans	Mid-Frequency Cetaceans	High-Frequency Cetaceans	Phocid Pinnipeds	Otariid Pinnipeds	
a	1	1.6	1.8	1	2	
b	2	2	2	2	2	
f ₁	0.2	8.8	12	1.9	0.94	
f ₂	19	110	140	30	25	
C	0.13	1.2	1.36	0.75	0.64	
Adjustment (dB) [†]	-12.44	-60.85	-70.00	-30.09	-36.69	
 OVERRIDE Using LDEO Modeling						

[†]For LF cetaceans, the adjustment factor (dB) is derived by estimating the radial distance of the 183-dB isopleth without applying the weighting function and a second time with applying the weighting function. Adjustment was derived using a propagation of 20*log₁₀ (Radial distance) and the modified farfield signature. For MF and HF cetaceans and pinnipeds, the difference between weighted–unweighted spectral source levels at each frequency was integrated to calculate adjustment factors (see spectrum levels in Figure A-20).

Amplitude spectral density from Farfield signature and effect of auditory weighting for the 5 hearing groups, one 40 cu.in 1900 LL airgun @ 12 m tow depth

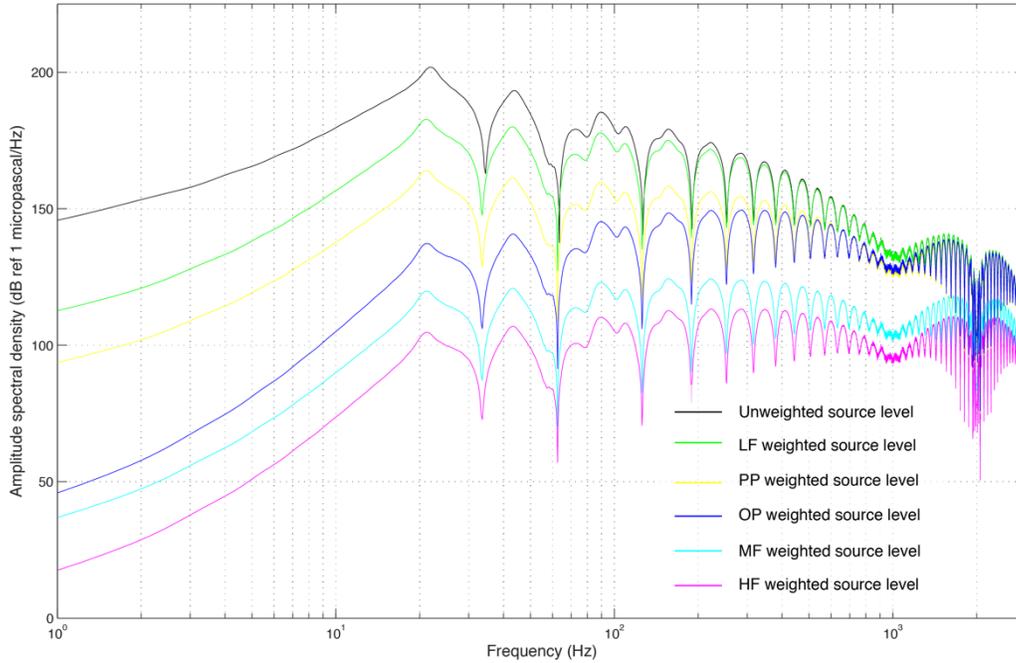


FIGURE A-20. Modeled amplitude spectral density of the 40 in³ airgun farfield signature. Amplitude spectral density before (black) and after (colors) applying the auditory weighting functions for LF, MF, and HF cetaceans, Phocid Pinnipeds (PP), and Otariid Pinnipeds (OP).

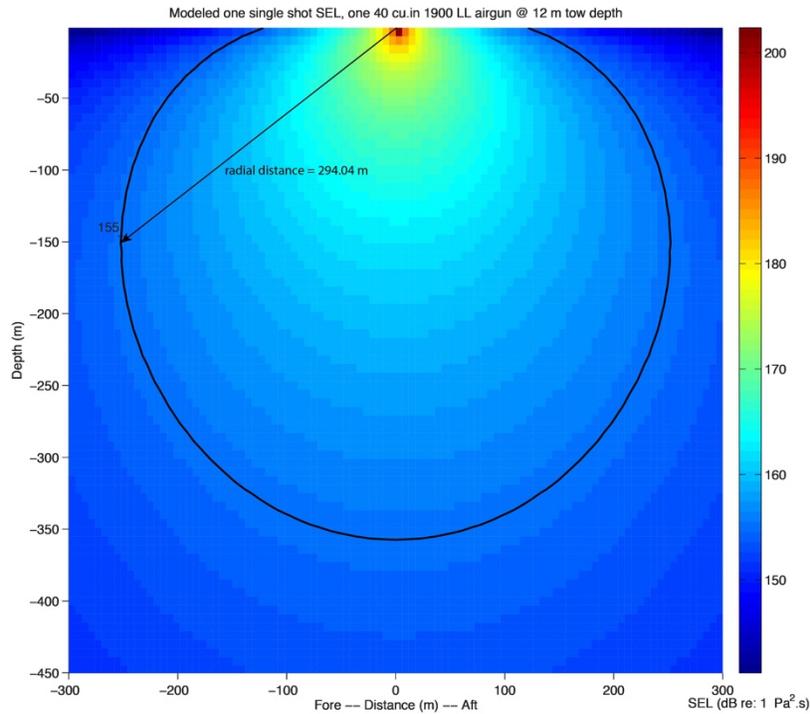


FIGURE A-21. Modeled received sound levels (SELs) in deep water from one 40-in³ airgun at a 12-m tow depth. The plot provides the distance from the geometrical center of the source array to the 155-dB SEL isopleth (294.04 m).

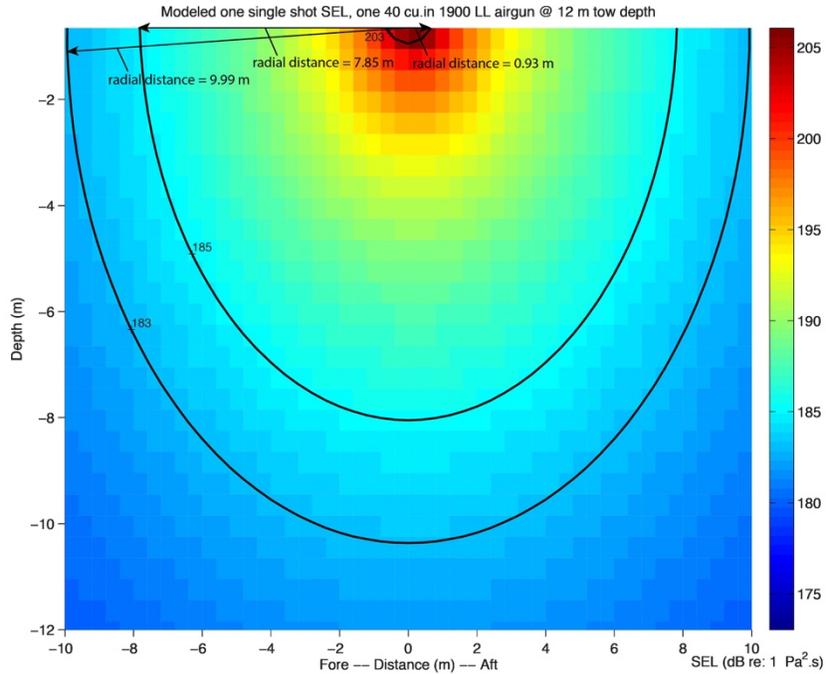


FIGURE A-22. Modeled received sound levels (SELs) in deep water from one 40-in³ airgun at a 12-m tow depth. The plot provides the distance from the geometrical center of the source array to the 183-, 185-, and 203-dB SEL isopleths.

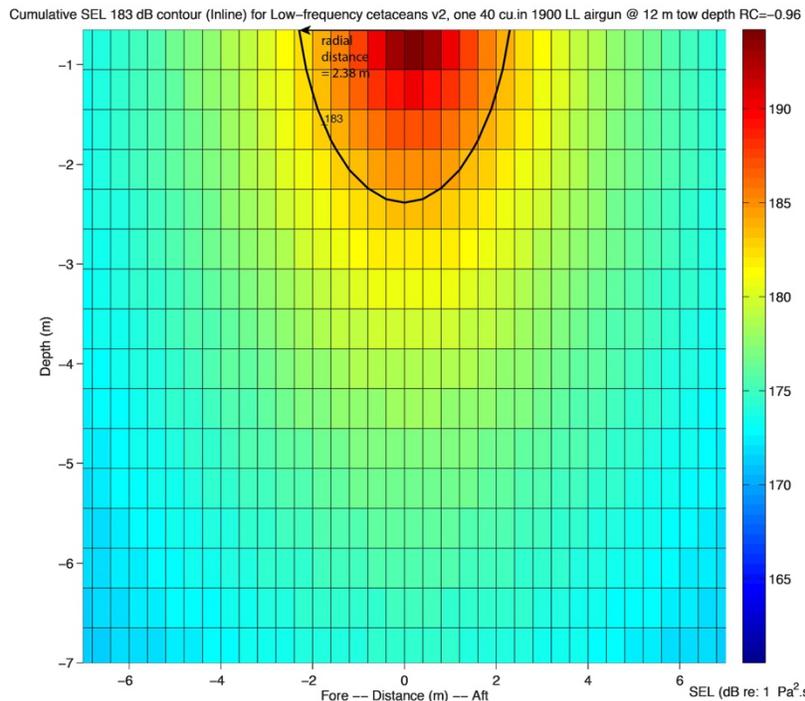


FIGURE A-23. Modeled received sound exposure levels (SELs) from one 40-in³ mitigation at a 12-m tow depth, after applying the auditory weighting function for the LF cetaceans hearing group following the NMFS Technical Guidance. The plot provides the radial distance to the 183-dB SEL_{cum} isopleth for one shot. The difference in radial distances between Fig. A-21 and this figure allows us to estimate the adjustment in dB.

TABLE A-11. NMFS Level A acoustic thresholds (Peak SPL_{flat}) for impulsive sources for marine mammals and predicted distances to Level A thresholds for various marine mammal hearing groups that could be received from the 40-in³ airgun during the proposed seismic surveys in the Northeast Pacific Ocean.

Hearing Group	Low-Frequency Cetaceans	Mid-Frequency Cetaceans	High-Frequency Cetaceans	Phocid Pinnipeds	Otariid Pinnipeds
Peak Threshold	219	230	202	218	232
PTS Peak Isopleth (Radius) to Threshold (m)	1.76	0.51	12.5	1.98	0.40

N.A. means not applicable or not available.

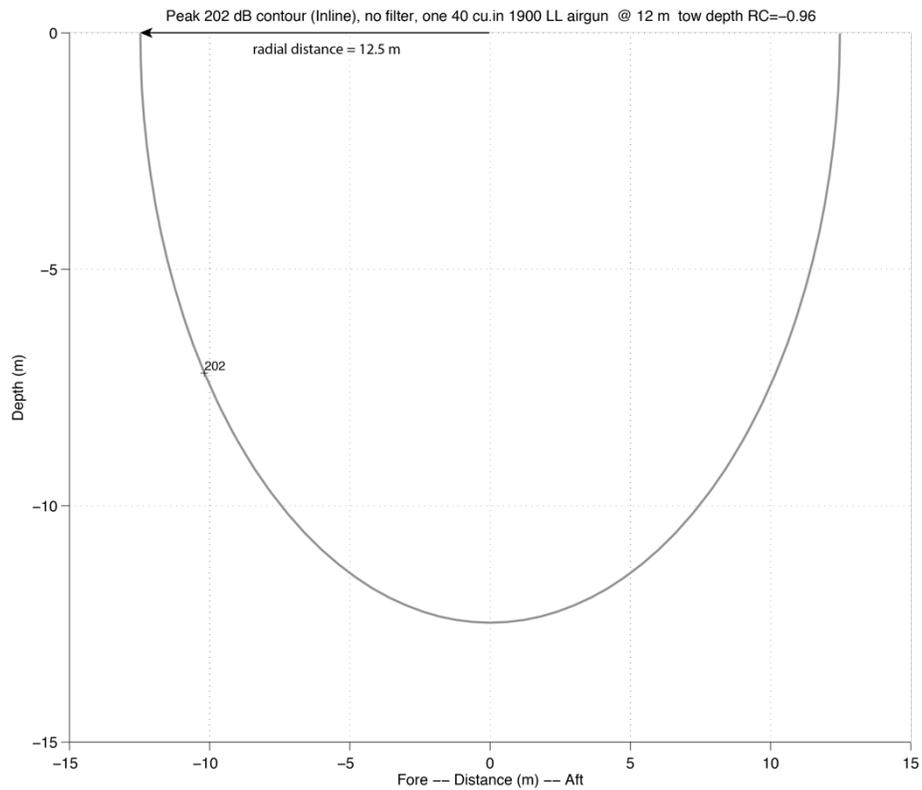


FIGURE A-24. Modeled deep-water received Peak SPL from one 40 in³ airgun at a 12-m tow depth. The plot provides the radial distance from the source geometrical center to the 202-dB Peak isopleth.

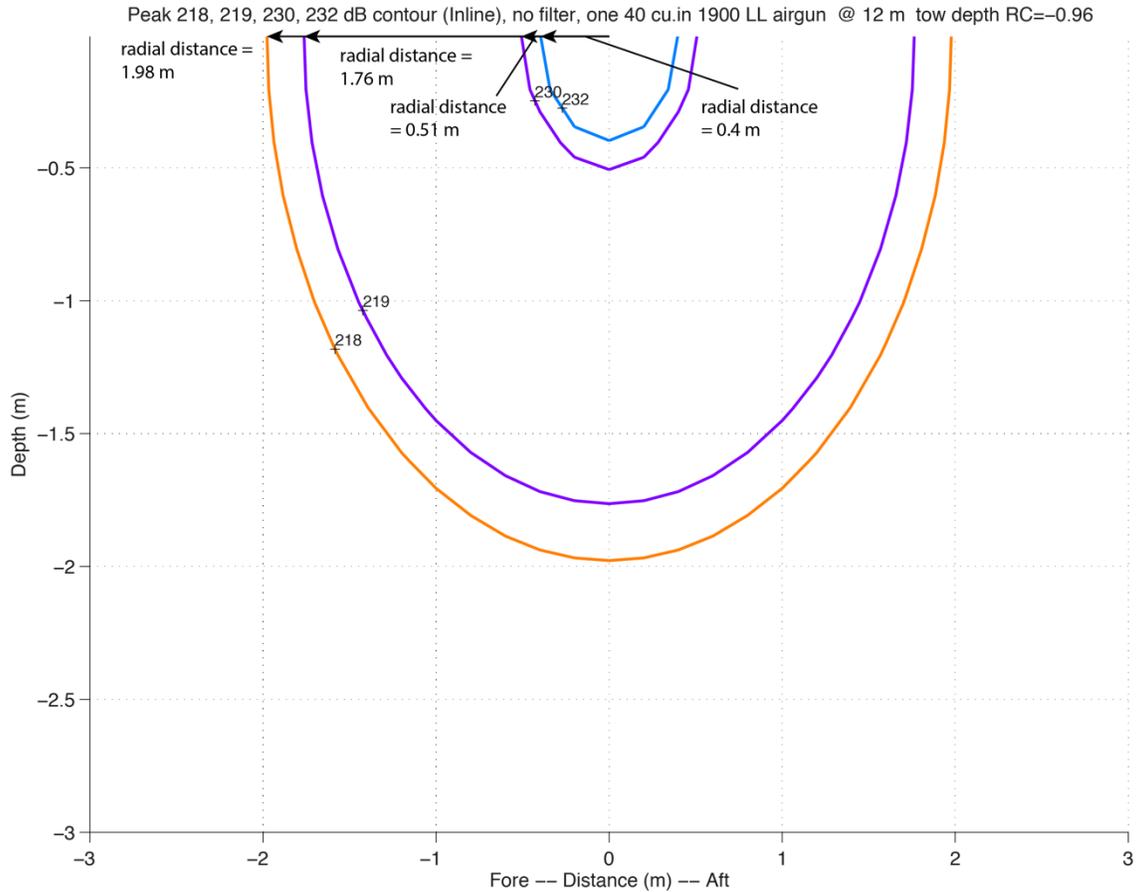


FIGURE A-25. Modeled deep-water received Peak SPL from one 40 in³ airgun at a 12-m tow depth. The plot provides the radial distances from the source geometrical center to the 218-, 219-, 230-, and 232-dB Peak isopleths.

TABLE A-12. Sea turtle thresholds recommended by NMFS. Predicted distances to which sound levels ≥ 195 - and 175-dB re 1 $\mu\text{Pa}_{\text{rms}}$ could be received during the proposed surveys in the Northeast Pacific Ocean in water depths >1000 m.

Source and Volume	Tow Depth (m)	Predicted distances (in m) to Received Sound Levels ¹	
		195 dB	175 dB
Single mitigation airgun, 40 in ³	12	8 (100 ²)	77
2 strings, 18 airguns, 3300 in ³	10	76 (100 ³)	814
4 strings, 36 airguns, 6600 in ³	12	181 ⁴	1864

¹ Distance is based on L-DEO model results.

² An EZ of 100 m would be used as the shut-down distance for sea turtles, as specified for low-energy sources in the PEIS.

³ Although this is not a low-energy source, an EZ of 100 m would be used as the shut-down distance for sea turtles.

⁴ This would be used as the shut-down distance for the EZ for the 36-airgun array.

Literature Cited

- Barton, P., J. Diebold, and S. Gulick. 2006. Balancing mitigation against impact: a case study from the 2005 Chicxulub seismic survey. **Eos Trans. Amer. Geophys. Union** 87(36), Joint Assembly Suppl., Abstr. OS41A-04. 23–26 May, Baltimore, MD.
- Crone, T.J., M. Tolstoy, and H. Carton. 2014. Estimating shallow water sound power levels and mitigation radii for the R/V *Marcus G. Langseth* using an 8 km long MCS streamer. **Geochem., Geophys., Geosyst.** 15(10):3793-3807.
- Crone, T.J., M. Tolstoy, and H. Carton. 2017. Utilizing the R/V *Marcus G. Langseth*'s streamer to measure the acoustic radiation of its seismic source in the shallow waters of New Jersey's continental shelf. PloS ONE 12(8):e0183096. <http://doi.org/10.1371/journal.pone.0183096>.
- Diebold, J.B., M. Tolstoy, P.J. Barton, and S.P. Gulick. 2006. Propagation of exploration seismic sources in shallow water. *Eos Trans. Amer. Geophys. Union* 87(36), Joint Assembly Suppl., Abstr. OS41A-03. 23–26 May, Baltimore, MD.
- Diebold, J.B., M. Tolstoy, L. Doermann, S.L. Nooner, S.C. Webb, and T.J. Crone. 2010. R/V *Marcus G. Langseth* seismic source: modeling and calibration. **Geochem. Geophys. Geosyst.** 11(12):Q12012. <http://doi.org/10.1029/2010GC003126>. 20 p.
- Finneran, J.J. 2016. Auditory weighting functions and TTS/PTS exposure functions for marine mammals exposed to underwater noise. Technical Report 3026. SSC Pacific, San Diego, CA.
- NMFS. 2016. Technical guidance for assessing the effects of anthropogenic sound on marine mammal hearing: underwater acoustic thresholds for onset of permanent and temporary threshold shifts. U.S. Dept. of Commer., NOAA. 178 p.
- NMFS. 2018. 2018 revision to: technical guidance for assessing the effects of anthropogenic sound on marine mammal hearing (version 2.0). Underwater thresholds for onset of permanent and temporary threshold shifts. Office of Protected Resources Nat. Mar. Fish. Serv., Silver Spring, MD. 167 p.
- Sivle, L.D., P.H., Kvadsheim, and M.A. Ainslie. 2014. Potential for population-level disturbance by active sonar in herring. **ICES J. Mar. Sci.** 72:558-567.
- Tolstoy, M., J. Diebold, L. Doermann, S. Nooner, S.C. Webb, D.R. Bohnstiehl, T.J. Crone, and R.C. Holmes. 2009. Broadband calibration of R/V *Marcus G. Langseth* four-string seismic sources. **Geochem. Geophys. Geosyst.** 10:Q08011. <https://doi.org/10.1029/2009GC002451>.
- USN (U.S. Navy). 2017. Criteria and thresholds for U.S. Navy Acoustic and Explosive Effects Analysis (Phase III). Technical Report prepared by the U.S. Navy.

APPENDIX B: MARINE MAMMAL TAKE CALCULATIONS

Species	Estimated Density (#/1000 km ²)	Population Size	Hearing Group	NMFS		Total Takes	Level A Takes	Level B Takes	% of Population (Total Takes)
				Level B 160 dB Ensonified Area (km ²)	Level A Ensonified Area (km ²)				
Mysticetes									
<i>North Pacific right whale</i>	0	500	LF	18861.26	1542.75	0	0	0	0
<i>Humpback whale</i>	1.83	1,918	LF	18861.26	1542.75	35	3	32	1.82%
<i>Minke whale</i>	1.30	636	LF	18861.26	1542.75	25	2	23	3.93%
<i>Sei whale</i>	0.40	519	LF	18861.26	1542.75	8	1	7	1.54%
<i>Fin whale</i>	4.25	9,029	LF	18861.26	1542.75	81	7	74	0.90%
<i>Blue whale</i>	1.10	1,647	LF	18861.26	1542.75	21	2	19	1.28%
Odontocetes									
<i>Sperm whale</i>	2.56	1,997	MF	18861.26	107.98	48	0	48	2.40%
<i>Pygmy/dwarf sperm whale</i>	1.63	4,111	HF	18861.26	976.71	31	2	29	0.75%
<i>Cuvier's and Mesoplodont beaked whales</i>	7.30	6,318	MF	18861.26	107.98	138	1	137	2.18%
<i>Baird's beaked whale</i>	0.82	2,697	MF	18861.26	107.98	15	0	15	0.56%
<i>Bottlenose dolphin</i>	0.003	1,924	MF	18861.26	107.98	0	0	0	N.A.
<i>Striped dolphin</i>	9.33	29,211	MF	18861.26	107.98	176	1	175	0.60%
<i>Short-beaked common dolphin</i>	124.89	969,861	MF	18861.26	107.98	2,356	13	2,343	0.24%
<i>Pacific white-sided dolphin</i>	17.43	26,814	MF	18861.26	107.98	329	2	327	1.23%
<i>Northern right-whale dolphin</i>	39.96	26,556	MF	18861.26	107.98	754	4	750	2.84%
<i>Risso's dolphin</i>	7.01	6,336	MF	18861.26	107.98	132	1	131	2.08%
<i>False killer whale</i>	0	N.A.	MF	18861.26	107.98	0	0	0	N.A.
<i>Killer whale</i>	0.92	483	MF	18861.26	107.98	17	0	17	3.52%
<i>Short-finned pilot whale</i>	0.25	836	MF	18861.26	107.98	5	0	5	0.60%
<i>Dall's porpoise</i>	43.95	25,750	HF	18861.26	976.71	829	43	786	3.22%
Pinnipeds									
<i>Northern fur seal</i>	10.30	634,710	Otariid	18861.26	93.46	194	1	193	0.03%
<i>Guadalupe fur seal</i>	2.90	20,000	Otariid	18861.26	93.46	55	0	55	0.28%
<i>Northern elephant seal</i>	30.90	179,000	Phocid	18861.26	260.55	583	8	575	0.33%

N.A. means not available.

APPENDIX C: ENSONIFIED AREAS FOR MARINE MAMMAL TAKE CALCULATIONS

Survey	Criteria	Relevant	Daily Ensonified	Total Survey		Total Ensonified
		Isopleth (m)	Area (km ²)	Days	25% Increase	Area (km ²)
2-D Survey	160-dB	6733	1346.90	3	1.25	5050.86
	LF Cetaceans	426.9	158.67	3	1.25	595.01
	HF Cetaceans	268.3	99.77	3	1.25	374.12
	Phocids	43.7	16.26	3	1.25	60.96
	MF Cetaceans	13.6	5.06	3	1.25	18.97
	Otariids	10.6	3.94	3	1.25	14.79
3-D Survey	160-dB	3758	690.52	16	1.25	13810.40
	LF Cetaceans	118.7	47.39	16	1.25	947.74
	HF Cetaceans	75.6	30.13	16	1.25	602.59
	Phocids	25.1	9.98	16	1.25	199.59
	MF Cetaceans	11.2	4.45	16	1.25	89.01
	Otariids	9.9	3.93	16	1.25	78.67