# Draft Environmental Assessment/Analysis of Marine Geophysical Surveys by R/V *Marcus G. Langseth* of the Puerto Rico Trench and Southern Slope of Puerto Rico, Northwest Atlantic Ocean

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**
2415 Eisenhower Avenue
Alexandria, VA 22314

by

**LGL Ltd., environmental research associates**
22 Fisher St., POB 280
King City, Ont. L7B 1A6

31 July 2023

LGL Report FA0221-0

# TABLE OF CONTENTS

Page

# LIST OF FIGURES

Page

# LIST OF TABLES

Page

# ABSTRACT

Researchers from Woods Hole Oceanographic Institution (WHOI), University of Texas Institute of Geophysics (UTIG), and University of Puerto Rico Mayagüez (UPRM), with funding from the U.S. National Science Foundation (NSF) and in collaboration with the United States Geological Survey (USGS) and researchers from the GEOMAR Helmholtz Centre for Ocean Research in Kiel, Germany, propose to conduct high-energy seismic surveys from the research vessel (R/V) *Marcus G. Langseth* (*Langseth*) of the Puerto Rico Trench and southern slope of Puerto Rico in the North Atlantic Ocean. Land seismometers would also be deployed during the high-energy seismic surveys. The USGS also proposes to conduct low-energy seismic surveys in the Caribbean Sea during the cruise. The Proposed Action, which includes the seismic surveys, would occur within the Exclusive Economic Zones (EEZ) and coastal zone of Puerto Rico, and the EEZs of the Dominican Republic, U.S. Virgin Islands, and British Virgin Islands. The surveys would use two different airgun configurations: (a) 36-airgun towed array with a total discharge volume of ~6600 in$^3$ in water depths ranging from ~100 m to 8400 m for the high-energy surveys, and (b) two 45/105-in$^3$ GI airguns with a total discharge volume of 90 in$^3$ off southern Puerto Rico in water depths ranging from ~100 m to 3000 m for the USGS low-energy surveys.

NSF 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. The seismic surveys would provide new constraints for examining earthquake and tsunami hazards associated with the Puerto Rico Trench region. The USGS has a mission to "provide reliable scientific information to describe and understand the Earth; minimize loss of life and property from natural disasters; manage water, biological, energy, and mineral resources; and enhance and protect our quality of life." The proposed surveys would support USGS research to understand earth processes and the natural hazards they pose to Puerto Rico and the Virgin Islands in order to increase public safety and reduce risk and economic loss.

This Draft Environmental Assessment/Analysis (EA) addresses NSF's requirements under the National Environmental Policy Act (NEPA) for the proposed NSF federal action within the U.S. EEZ and Executive Order 12114, "Environmental Effects Abroad of Major Federal Actions", for the proposed NSF federal action in foreign EEZs. Due to their involvement with the Proposed Action, the USGS requested to be a Cooperating Agency. As owner and operator of R/V *Langseth*, Lamont-Doherty Earth Observatory (L-DEO) of Columbia University, on behalf of itself, NSF, WHOI, UTIG, UPRM, and USGS have requested 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 and threatened species was included, this document will also be used to support ESA Section 7 consultations with NMFS. 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 Records of Decision (NSF 2012; USGS 2013), referred to herein as PEIS.

Numerous species of marine mammals inhabit the proposed marine project area in the North Atlantic Ocean. Under the U.S. ESA, several of these species are listed as ***endangered***, including the sei, fin, blue, and sperm whales, which are managed by NMFS. The Antillean manatee is listed as ***threatened*** and managed by the U.S. Fish and Wildlife Service (USFWS). However, as all activities would occur in water deeper than 100 m, manatees are not expected to be encountered during the proposed surveys. ESA-listed sea turtle species that could occur in the project area include the ***endangered*** leatherback and hawksbill sea turtles, the ***threatened*** Northwest Atlantic DPS of loggerhead turtle, the ***threatened*** olive ridley turtle, and the ***threatened*** North Atlantic and South Atlantic DPSs of green sea turtle. Five fish species listed under the ESA that could occur in the survey areas, including the ***endangered*** giant manta ray and smalltooth sawfish; and the ***threatened*** Nassau grouper, oceanic whitetip shark, and Central and Southwest Atlantic DPS of scalloped hammerhead shark. Both the U.S. and the non-U.S. populations of smalltooth shark are listed under the ESA and could occur in the proposed survey areas. The queen conch is proposed for listing under the ESA as ***threatened*** and could also occur in the survey areas. The ***threatened*** roseate tern is the only ESA-listed seabird that could be encountered in the area. The black-capped petrel is proposed for listing as threatened. In addition, there are eight terrestrial ESA-listed species that could occur near the land seismometer deployments, these include the ***endangered*** Puerto Rican broad-winged hawk, Puerto Rico nightjar, Puerto Rican parrot, Puerto Rican sharp-shinned hawk, Puerto Rican boa, and the flowering plans Palo De Ramon, Palo De Rosa, and West Indian walnut.

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 (MBES) and sub-bottom profiler (SBP) 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 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; two dedicated observers maintaining a visual watch during all daytime airgun operations; two observers before and during ramp ups during the day; PAM via towed hydrophones during both day and night to complement visual monitoring during the high-energy surveys; and shutdowns when marine mammals are detected in or about to enter designated EZ. The acoustic source would also be powered down (or if necessary, shut down) in the event a sea turtle or an ESA-listed seabird would be observed diving or foraging within the designated EZ. Observers would also watch for 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. 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 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, seabirds, fish, the populations to which they belong, or their habitats. NSF followed the National Oceanic and Atmospheric Administration's (NOAA) *Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing* (NMFS 2016a, 2018a) to estimate Level A takes for 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 |
| ADCP | Acoustic Doppler Current Profiler |
| AEP | Auditory Evoked Potential |
| AFTT | Atlantic Fleet Testing and Training |
| AMVER | Automated Mutual-Assistance Vessel Rescue |
| CBD | Convention on Biological Diversity |
| CFMC | Caribbean Fishery Management Council |
| CITES | Convention on International Trade in Endangered Species |
| DAA | Detailed Analysis Area |
| dB | decibel |
| DFO | Canadian Department of Fisheries and Oceans |
| DoN | Department of the Navy |
| DPS | Distinct Population Segment |
| EA | Environmental Assessment/Analysis |
| EBSA | Ecologically or Biologically Significant Marine Areas |
| EFH | Essential Fish Habitat |
| EIS | Environmental Impact Statement |
| EO | Executive Order |
| ESA | (U.S.) Endangered Species Act |
| EZ | Exclusion Zone |
| FAO | Food Agricultural Organization |
| 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 |
| IPaC | Information for Planning and Consultation |
| IRIS | Incorporated Research Institutions for Seismology |
| ITS | Incidental Take Statement |
| IUCN | International Union for the Conservation of Nature |
| IWC | International Whaling Commission |
| JNCC | Joint Nature Conservation Committee |
| kHz | kilohertz |
| km | kilometer |
| kt | knot |
| L-DEO | Lamont-Doherty Earth Observatory |
| LFA | Low-frequency Active (sonar) |
| LME | Large Marine Ecosystem |
| 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 |
| NAMMCO | North Atlantic Marine Mammal Commission |
| NEPA | National Environmental Policy Act |
| NMFS | (U.S.) National Marine Fisheries Service |
| nmi | nautical mile |
| NOAA | National Oceanic and Atmospheric Administration |
| NRC | (U.S.) National Research Council |
| NSF | National Science Foundation |
| OBS | Ocean Bottom Seismometer |
| OBSIC | Ocean Bottom Seismometer Instrument Center |
| OEIS | Overseas Environmental Impact Statement |
| p or pk | peak |
| PASSCAL | Portable Array Seismic Studies of the Continental Lithosphere |
| PEIS | Programmatic Environmental Impact Statement |
| PI | Principal Investigator |
| PTS | Permanent Threshold Shift |
| PSO | Protected Species Observer |
| rms | root-mean-square |
| R/V | research vessel |
| s | second |
| SBP | Sub-bottom Profiler |
| SEL | Sound Exposure Level (a measure of acoustic energy) |
| SPL | Sound Pressure Level |
| SOSUS | (U.S. Navy) Sound Surveillance System |
| SWFSC | Southwest Fisheries Science Center |
| SWoT | The State of the World’s Sea Turtles |
| t | tonnes |
| TTS | Temporary Threshold Shift |
| U.K. | United Kingdom |
| UNEP | United Nations Environment Programme |
| UNESCO | United Nations Educational, Scientific and Cultural Organization |
| UPRM | University of Puerto Rico Mayagüez |
| 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 |
| WHOI | Woods Hole Oceanographic Institution |
| y | year |

# I PURPOSE AND NEED

This Draft Environmental Assessment/Analysis (EA) was prepared pursuant to the National Environmental Policy Act (NEPA) and Executive Order 12114, "Environmental Effects Abroad of Major Federal Actions". Due to their involvement with the Proposed Action, the United States Geological Survey (USGS) requested to be a Cooperating Agency. The Draft 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 Records of Decision (NSF 2012; USGS 2013), referred to herein as the PEIS. The purpose of this Draft 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 Draft 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 marine invertebrates. The Draft EA will also be used in support of other regulatory processes, including an application for an Incidental Harassment Authorization (IHA) and Section 7 consultations under the Endangered Species Act (ESA) with the National Marine Fisheries Service (NMFS). The IHA would allow the non-intentional, non-injurious "take by harassment" of small numbers of marine mammals[1] during the proposed seismic surveys. Following the NOAA *Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing* (NMFS 2016a, 2018a), 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.

The USGS is a science mission agency within the U.S. Department of the Interior and has no regulatory responsibility. The USGS mission is to "provide reliable scientific information to describe and understand the Earth; minimize loss of life and property from natural disasters; manage water, biological, energy, and mineral resources; and enhance and protect our quality of life." Additional details on USGS are described in Chapter 1 of the PEIS.

## 1.2 Purpose of and Need for the Proposed Action

As noted in the PEIS, § 1.3, NSF and USGS have 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 high-energy (36-airgun array) seismic surveys would be to provide new

---

[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.

constraints for examining earthquake and tsunami hazards associated with the Puerto Rico Trench region. The high-energy surveys 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. The low-energy (2-GI guns) seismic surveys would support USGS research to understand Earth processes and the natural hazards they pose to Puerto Rico and the Virgin Islands in order to increase public safety and reduce risk and economic loss.

## 1.3 Background of NSF-funded Marine Seismic Research

The background of NSF-funded and USGS conducted marine seismic research is described in § 1.5 and § 1.6 of the PEIS, respectively.

## 1.4 Regulatory Setting

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

- Executive Order 12114 – *Environmental effects abroad of major Federal actions*;
- *National Environmental Protection Act* (NEPA) of 1969 (42 United States Code [USC] §4321 *et seq.*); the Council on Environmental Quality (CEQ) Regulations for Implementing the Procedural Provisions of NEPA (Title 40 Code of Federal Regulations [CFR] §§ 1500–1508 (1978 *et seq*.); NSF procedures for implementing NEPA and CEQ regulations (45 CFR 640);
- *Marine Mammal Protection Act* (MMPA) of 1972 (16 USC 1631 *et seq*.);
- *Endangered Species Act* (ESA) of 1973 (16 USC ch. 35 §1531 *et seq.*);
- *National Historic Preservation Act* (NHPA) (Public Law 89-665; 54 USC 300101 *et seq.*);
- *Coastal Zone Management Act* (CZMA) of 1972 (16 USC §§1451 *et seq.*); and
- *Magnuson-Stevens Fishery Conservation and Management Act* – Essential Fish Habitat (EFH) (Public Law 94-265; 16 USC ch. 38 §1801 *et seq*.).

# II ALTERNATIVES INCLUDING PROPOSED ACTION

In this Draft EA, two alternatives are evaluated: (1) the proposed seismic surveys and associated issuance of an associated IHA and (2) No Action alternative. Two additional 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.

### 2.1.1 Project Objectives and Context

Researchers from Woods Hole Oceanographic Institution (WHOI), University of Texas Institute of Geophysics (UTIG), and University of Puerto Rico Mayagüez (UPRM), have proposed to conduct seismic surveys using R/V *Langseth* of the Puerto Rico Trench in the North Atlantic Ocean (Fig. 1). Dr. I. Grevemeyer, GEOMAR Helmholtz Centre for Ocean Research (GEOMAR), would collaborate with the Principal Investigators (PIs) of the Puerto Rico Trench project and would contribute ultra-deep sea Ocean Bottom Seismometers (OBSs) necessary for achieving the objectives. Although not funded through

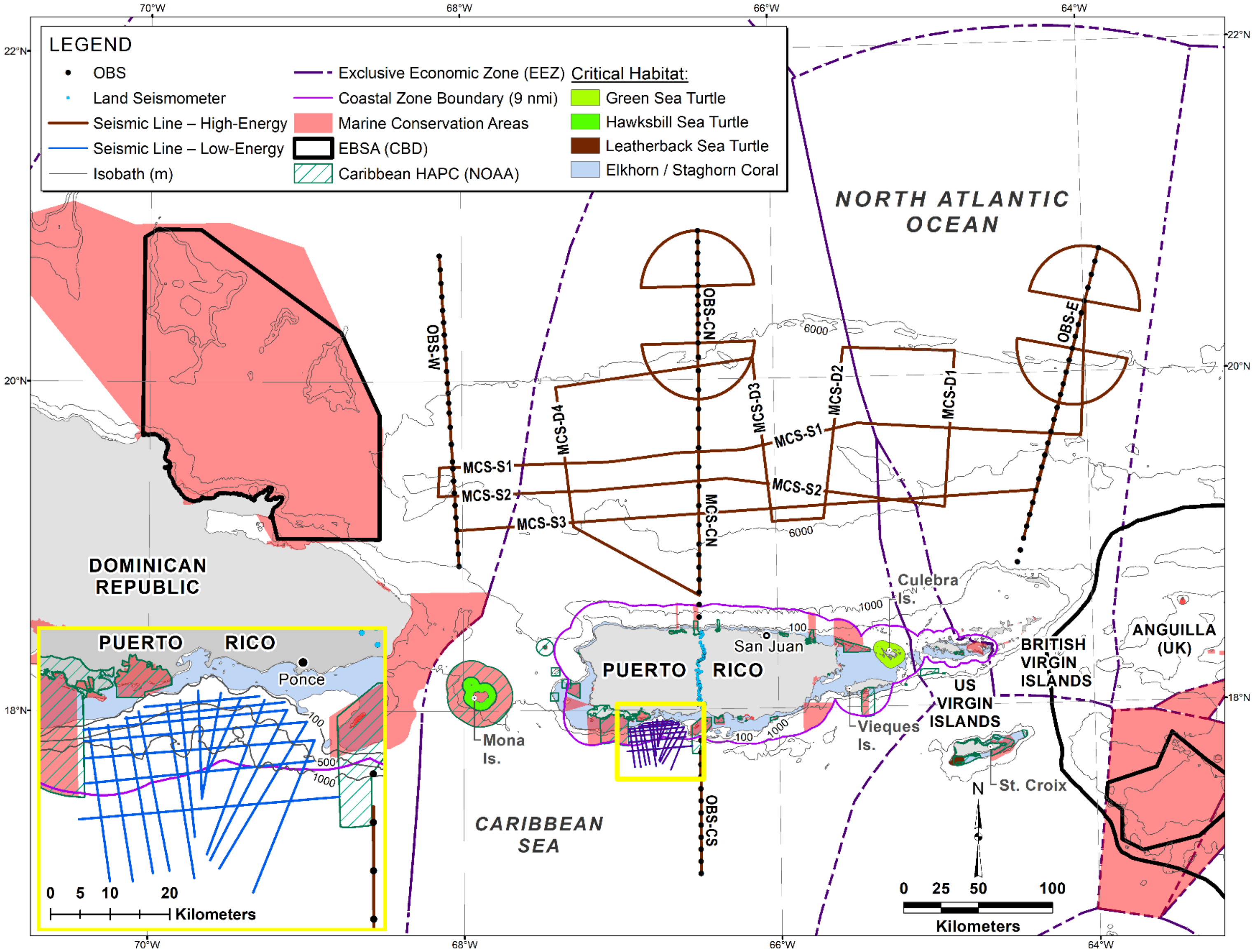


FIGURE 1. Location of the proposed seismic surveys (low-energy USGS surveys shown in inset), OBS deployments, land seismometer locations, marine conservation areas, and marine critical habitat.

NSF, United States Geological Survey (USGS) researchers would collaborate on proposed low energy surveys of the southern slope of Puerto Rico in the North Atlantic Ocean.

The main goal of the high-energy seismic program proposed by the PIs Drs. J.P. Canales (WHOI), S. Han (UTIG), and E. Vanacore (UPRM) is to investigate the Puerto Rico Trench, its outer rise, and across the island of Puerto Rico, and provide data necessary to illuminate the depth, geometry, and physical properties of the seismogenic fault interface between the subducting Atlantic plate and the overlying accretionary wedge/Puerto Rico arc/Caribbean plate, as well as seismogenic structures in the accretionary wedge and submarine slopes of the island of Puerto Rico. The proposed study would provide new constraints for examining earthquake and tsunami hazards associated with the Puerto Rico Trench. The low-energy seismic surveys proposed by PI U. ten Brink (USGS) would be located over the 2019–2020 area of seismic activity in the Caribbean Sea to define the geometry of the faults that ruptured and produced earthquakes of magnitude Mw≤6.4 and other potential seismogenic structures. To achieve project goals of the seismic surveys, the PIs propose to utilize the airgun capabilities of R/V *Langseth*, as well as Ocean Bottom Seismometers (OBS) and land seismometers for the high-energy surveys.

The Puerto Rico Trench is a highly oblique subduction zone, where old Atlantic plate subducts under the Caribbean plate at a slow rate (<20 mm/yr). The Puerto Rico Trench is associated with anomalous, and hitherto unexplained characteristics, such as the widest trench (below 6000 m) and the lowest gravity anomaly on Earth, and anomalous subsidence of the north coast of Puerto Rico. Furthermore, the slab may be segmented and perhaps torn. This proposed experiment is aimed at addressing three key questions: (1) What is the shallow geometry of the subducting slab and its lateral continuity along the 500-km section of the trench? The information gathered would help inform the potential for the Puerto Rico Trench to generate a mega-earthquake and mega-tsunami, similar to the 2004 Sumatra earthquake and tsunami, impacting the Caribbean and U.S. Atlantic margins. (2) What is the degree and spatial extent of alteration of the Atlantic lithosphere entering the Puerto Rico Trench? Comparison with other subduction zones would allow quantification of the water and other volatiles inputs into Atlantic subduction zones. (3) Does the oceanic bivergent thrust system represent double-sided subduction or a crustal retro-wedge of one-sided subduction? The latter structure could be formed in response to compression of the rigid arc crust, with implications for earthquake potential of the southern flank of Puerto Rico. This project would determine the detailed seismic structure and properties of the crust and slab of the entire arc and the seismically active region of Puerto Rico and the Virgin Islands and has broad implications for earthquake hazard assessment in the subduction zone off Puerto Rico.

## 2.1.2 Proposed Activities

### 2.1.2.1 Location of the Survey Activities

The proposed marine seismic surveys would occur within ~17–21°N, 63.6–68.2°W. Representative survey tracklines are shown in Figure 1. As described further in this document, however, some deviation in actual tracklines, 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 within Exclusive Economic Zones (EEZ) of Puerto Rico, U.S. Virgin Islands, British Virgin Islands, and the Dominican Republic, in water depths ranging from ~100–8400 m. The closest approach of the proposed low-energy survey lines to land on the south side of Puerto Rico is ~2.5 km from Isla de Ratones (Isla Piñero), ~3.4 km from Cayo Maria Langa, and ~3 km from Cayo Aurora. The closest approach of the high-energy survey lines to the coast of Puerto Rico is ~22 km, 28 km to the British Virgin Islands, 42 km to Dominican Republic, and 77 km to the U.S. Virgin Islands.

### 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 high-energy surveys would involve one source vessel, R/V *Langseth*, which would tow a 36-airgun array with a discharge volume of ~6600 $\text{in}^3$ at a depth of 12 m. The receiving system would consist of a 15-km long solid-state hydrophone streamer, 31 short-period OBSs, and 10 GEOMAR ultra-deep-water broadband OBSs. The airguns would fire at a shot interval of 50 m (~24 s) during multi-channel seismic (MCS) reflection surveys with the hydrophone streamer and at a 400-m (155 s) interval during OBS seismic refraction surveys. For the low-energy surveys, two 45/105-$\text{in}^3$ GI airguns with a total discharge volume of 90 $\text{in}^3$ would be towed at a depth of 3 m from the single source vessel, R/V *Langseth*. The receiving system would consist of a 150-m long solid-state hydrophone streamer. As the airgun arrays are towed along the survey lines, the hydrophone streamer would transfer the data to the on-board processing system, and the OBSs would receive and store the returning acoustic signals internally for later analysis. The following generally describes the proposed data collection plan:

> (1) Acquisition of wide-angle reflection/refraction seismic data using OBSs would occur along four major transects: Central-North (OBS-CN), Central-South (OBS-CS), East (OBS-E), and West (OBS-W).
>
> (2) MCS data would be acquired along transects MCS-D1, D2, D3, and D4 and along transects MCS-S1, S2, and S3. MCS-CN, -W, and -E coinciding with the OBS profiles north of the island; thus, those transects would be acquired twice (once with OBS and once with MCS). The Central South line (OBS-CS) would only be acquired once during OBS refraction surveys.
>
> (3) Low-energy MCS surveys would occur on the southwestern flank of Puerto Rico over the location of recent seismic activity.
>
> (4) An array of short-period nodal land seismometers would be deployed on Puerto Rico on properties along PR-149 to connect the Central and Central South OBS marine profiles.

Approximately 4630 km of seismic acquisition are proposed. During the high-energy surveys, ~4070 km of transect lines would be surveyed (~2565 km of 2-D MCS seismic reflection data and 1505 km of OBS refraction data); the low-energy USGS surveys would consist of ~560 line km. 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. All of the high-energy surveys with the 36-airgun array would occur in deep water, >1000 m deep. For the low-energy USGS surveys conducted with the 2-GI airguns, 43% would occur in intermediate-depth water 100–1000 m deep, and 57% would take place in deep water >1000 m; no effort would occur in shallow water (<100 m deep).

In addition to the operations of the airgun array, other acoustic sources, including 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; acoustic pingers would also be used. All planned marine-based 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

Land seismometers would be deployed ~2 weeks prior to the start of marine seismic operations. The low-energy USGS surveys, consisting of ~3 days of seismic operations, would then take place. This would be followed by a 42-day cruise for the proposed high-energy surveys with the 36-airgun array, including ~21 days of seismic operations, 20 days for equipment deployment/recovery, and 2 days of transit/contingency time. Operational order may change due to unforeseen events; equipment deployment and recovery times would vary and occur anytime during the planned survey. R/V *Langseth* would likely leave out of and return to port in San Juan, Puerto Rico, during fall 2023. L-DEO strives 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.

### 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 with the 36-airgun array would be ~4.1 kt (~7.6 km/h) during MCS seismic reflection surveys and 5.0 kt (~9.3 km/h) during OBS seismic refraction surveys. When R/V *Langseth* is towing the airgun array and hydrophone streamer, the turning rate of the vessel is limited to five degrees per minute. Thus, the maneuverability of the vessel is limited during operations with the streamer.

### 2.1.2.5 Airgun Description

During the MCS seismic reflection and OBS seismic refraction surveys, R/V *Langseth* would tow four strings with 36 airguns (plus 4 spares); the strings are spaced 8 m apart, with the airguns and 1 spare airgun spaced 2-3.5 m along each string. The airgun array consists of a mixture of Bolt 1500LL and Bolt 1900LLX airguns. The four airgun strings would be distributed across an area of ~24x16 m behind the *Langseth* and would be towed ~140 m behind the vessel. During the high-energy surveys, all four strings, totaling 36 active airguns with a total discharge volume of 6600 in$^3$, would be used. The array would be towed at a depth of 12 m, and the shot interval would be 50 m (~24 s) during MCS seismic reflection surveys and 400 m (155 s) during OBS seismic refraction surveys. The airgun array and its source level and frequency components are described in § 2.2.3.1 of the PEIS and summarized below, and the airgun configuration is illustrated in Figure 2-11 of the PEIS. During the USGS low-energy surveys, R/V *Langseth* would tow a 2 GI-airgun cluster in true GI (45/105 in$^3$) mode as the seismic source, with a total discharge volume of 90 in$^3$. The two inline GI airgun would be spaced 2.46 m apart. The array would be towed at a depth of 3 m, and the shot interval would be 6.25 m. The firing pressure of the airguns is 1900 psi. During firing, a brief (~0.1 s) pulse of sound is emitted. The airguns would be silent during the intervening periods.

**<u>36-Airgun Array Specifications</u>**

| | |
|---|---|
| Energy Source | Thirty-six 1900 psi Bolt airguns of 40–360 in$^3$,<br>in four strings each containing nine operating airguns |
| Source output (downward) | 0-pk is 84 bar-m (259 dB re 1 μPa·m);<br>pk-pk is 177 bar·m (265 dB) |
| Air discharge volume | ~6600 in$^3$ |
| Dominant frequency components | 2–188 Hz |

**2 GI Airgun Array Specifications**

| | |
|---|---|
| Energy Source | Two 45/105 in$^3$ GI airguns |
| Source output (downward) | 0-pk is 3.6 bar-m (231.1 dB re 1 μPa·m);<br>pk-pk is 7.1 bar·m (237 dB re 1 μPa·m) |
| Air discharge volume | ~90 in$^3$ |
| Gun positions used | Two inline GI guns 2.46 m apart |
| Dominant frequency components | 2–188 Hz |

### 2.1.2.6 Seismometer Description

Four refraction lines would be acquired using OBSs: East, West, and Central-North, and Central-South. Refraction data would be acquired using 31 short-period OBSs from the Ocean Bottom Seismometer Instrument Center (OBSIC) at WHOI. Short-period OBSs would be deployed at a total of 69 sites in water depths <6000 m by R/V *Langseth*. Fifteen ultra-deep-water OBSs provided by GEOMAR would be deployed at a total of 25 sites in water depths of ~6000–8400 m. Following refraction shooting of one line, OBSs on that line would be recovered, serviced, and redeployed on a subsequent refraction line. The OBSIC OBSs have a height of ~1 m, a diameter of ~0.5 m, and a weight ~22 kg; the steel anchor is 30.5 cm x 38 cm x 2.5 cm high and weighs ~24 kg. The GEOMAR OBSs have a height of ~0.5 m, a diameter of ~1 m, and a weight ~60 kg, including the steel anchor. All OBSs would be recovered by the end of the survey. To retrieve the OBSs, the instrument is released via an acoustic release system to float to the surface from the anchor, which is not retrieved.

In addition, an array of ~100 short-period nodal land seismometers from the Incorporated Research Institutions for Seismology (IRIS) Portable Array Seismic Studies of the Continental Lithosphere (PASSCAL) Instrument Center at New Mexico Tech would be located on the island of Puerto Rico to connect the OBS-CN and -CS marine profiles (Fig. 1). The deployment of the instruments would follow the road PR-149 at ~500-m intervals. The instruments would be deployed in previously disturbed areas on private land with permission of the landowners. The nodal seismometers are all-in-one instruments that combine seismic sensors with their dataloggers in a single, easily-deployed unit. Installation would consist of a 0.5-m deep hole for the node to be installed by direct burial. The short-period seismometers would be deployed for ~2 months overlapping in time with R/V *Langseth* seismic activities. Upon removal, all holes would be refilled to restore the sites to as close as the original condition as possible.

### 2.1.2.7 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. The ocean floor would be mapped with the Kongsberg EM 122 MBES and a Knudsen Chirp 3260 SBP. These sources are described in § 2.2.3.1 of the PEIS as well below. 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 wire and/or anchor which are not retrieved.

The MBES is a hull-mounted system operating at 10.5–13 kHz (usually 12 kHz). The transmitting beamwidth is one or two degrees fore-aft and 150 degrees (maximum) athwartship or perpendicular to the ship's line of travel. The maximum sound source level is 242 dB re 1 μPa-m. Each ping consists of eight (in water > 1000 m) or four (in water <1000 m) successive fan-shaped transmissions, each ensonifying a sector that extends one degree fore-aft. Continuous-wave signals increase from 2–15 milliseconds long in water depths up to 2600 m, and frequency modulated chirp signals up to 100 milliseconds long are used in water >2600 m. The successive transmissions span an overall cross-track angular extent of ~150 degrees, with two millisecond gaps between the pings for successive sectors.

The Knudsen 3260 SBP is normally operated to provide information about the near sea floor sedimentary features and the bottom topography that is mapped simultaneously by the MBES. The beam is transmitted as a 27-degree cone, which is directed downward by a 3.5-kHz transducer in the hull of R/V *Langseth*. The nominal power output is 10 kilowatts, but the actual maximum radiated power is 3 kilowatts or 222 $dB_{rms}$ re 1 µPa at 1 m. The ping duration is up to 64 milliseconds, and the ping interval is one second. A common mode of operation is to broadcast five pulses at one-second intervals followed by a five-second pause. The SBP is capable of reaching depths of 10,000 m.

A Teledyne RDI 75 kHz Ocean Surveyor ADCP would be used to measure water current velocities. It would operate at a frequency of 75 kHz, with a maximum source level of 224 dB re 1µPa-1 m over a conically-shaped 30° beam, a maximum pulse duration of 37ms, and a ping rate of 0.7 Hz.

## 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 which 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. However, the scientific objectives for the proposed high-energy surveys could not be met using a smaller source. A large airgun source is required to penetrate the crustal depths that would address the project goals. The Puerto Rico Trench is one of the deepest in the world (8.4 km) and the widest (below 6000 m depth) on the planet. Imaging crustal and upper mantle structures that lie many kilometers beneath such deep seafloor requires a well-tuned, high-volume airgun array that can generate acoustic pulses in a broad band of frequencies that propagate through such depths with sufficient amplitude to be detected. Smaller airgun arrays do not have the capability to generate pulses suitable for such very deep, long-offset imaging. For the USGS seismic surveys of the southwestern flank of Puerto Rico in the Caribbean Sea, a low-energy source of 2 GI airguns was determined to be sufficient to meet the project goals.

***Survey Location and Timing*****.—**The PIs designed the surveys to avoid high-energy source survey tracklines and Level B predicted ensonified areas from entering the Puerto Rico coastal zone. The PIs worked with L-DEO and 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*. Although most marine mammals are expected to occur in the proposed survey areas throughout the year, the humpback whale is common in the wider region seasonally from December through March. Hurricane season typically occurs during July–September). Fall (October–December) was determined to be the most practical season for the proposed surveys based on the occurrence of marine mammals, weather conditions, other operational requirements, and availability of researchers.

***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 the exclusion zones (EZ) for Level A takes (for the 36-airgun array, only) and for the Level B (160 dB re 1µPa$_{rms}$) threshold (for the 36-airgun and 2-GI airgun arrays). The background information and methodology for this are provided in Appendix A. L-DEO model results are used to determine the 160-dB$_{rms}$ radius for the various airgun sources down to a maximum depth of 2000 m (see Appendix A), as animals are generally not anticipated to dive below 2000 m (Costa and Williams 1999). The radii for intermediate water depths (100–1000 m) are derived from the deep-water ones by applying a correction factor of 1.5.

Table 1 shows the distances at which the 160-dB re 1µPa$_{rms}$ sound levels are expected to be received for the 36-airgun array, a single 40 in$^3$ (mitigation) airgun, and a 2-GI airgun cluster. The 160-dB level is the behavioral disturbance criterion (Level B) that is used by NMFS to estimate anticipated takes for marine mammals. Table 1 also shows the distances at which the 175-dB re 1µPa$_{rms}$ sound level is expected to be received for the various airgun sources; this level is used by NMFS, based on US DoN (2017), to determine behavioral disturbance for turtles.

The NSF and USGS PEIS defined a low-energy source as any towed acoustic source whose received level is ≤180 dB re 1 µPa$_{rms}$ (the Level A threshold under the former NMFS acoustic guidance) at 100 m, including any single or any two GI airguns and a single pair of clustered airguns with individual volumes of ≤250 in$^3$. In § 2.4.2 of the PEIS, Alternative B (the Preferred Alternative) conservatively applied a 100-m exclusion zone (EZ) for all low-energy acoustic sources in water depths >100 m. Consistent with the PEIS, that approach is used here for the pair of 45/105 in$^3$ GI airguns in all water depths. A fixed 160-dB "Safety Zone" was not defined for the same suite of low-energy sources in the NSF and USGS PEIS.

The thresholds for permanent threshold shift (PTS) onset or Level A Harassment (injury) for marine mammals and sea turtles 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 available 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) (NMFS 2016a, 2018a), and sea turtles (DoN 2017). Per 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 Level A takes and threshold distances for marine mammals. Here, SEL$_{cum}$ is used for turtles and LF cetaceans, and Peak SPL is used for all other marine mammal hearing groups (Table 2).

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). We have proposed monitoring and mitigation measures that have been required by NMFS for other similar recent high- and low-energy seismic surveys. Enforcement of mitigation zones via power and shutdowns would be implemented as described below or as otherwise required by regulators.

TABLE 1. Level B. Predicted distances to which sound levels ≥160-dB re 1 μPa$_{rms}$ could be received during the proposed surveys off Puerto Rico. The 160-dB criterion applies to all hearing groups of marine mammals, and the 175-dB criterion applies to sea turtles.

| Source and Volume | Tow Depth (m) | Water Depth (m) | Predicted distances (in m) to the 160-dB Received Sound Level | Predicted distances (in m) to the 175-dB Received Sound Level |
|---|---|---|---|---|
| Single Bolt airgun, 40 in$^3$ | 12 | >1000 m | 431[1] | 77[1,3] |
| | | 100–1000 m | 647[2] | 116[2] |
| 4 strings, 36 airguns, 6600 in$^3$ | 12 | >1000 m | 6,733[1] | 1,864[1] |
| | | 100–1000 m | 10,100[2] | 2,796[2] |
| Two 45/105 in$^3$ GI airguns | 3 | >1000 m | 438[1] | 78[1,3] |
| | | 100–1000 m | 657[2] | 117[2] |

[1] Distance is based on L-DEO model results. [2] Distance is based on L-DEO model results with a 1.5 × correction factor between deep and intermediate water depths. [3] An EZ of 150 m would be used as the shut-down distance for sea turtles and ESA listed seabirds in all water depths.

TABLE 2. Level A threshold distances for different marine mammal hearing groups and sea turtles for the 36-airgun array based on a shot interval of 50 m[1]. Consistent with NMFS (2016a, 2018), the largest distance (in bold) of the dual criteria (SEL$_{cum}$ or Peak SPL$_{flat}$) was used to calculate Level A takes and threshold distances.

| | Level A Threshold Distances (m) for Various Hearing Groups | | | | | |
|---|---|---|---|---|---|---|
| | Low-Frequency Cetaceans | Mid-Frequency Cetaceans | High-Frequency Cetaceans | Phocid Pinnipeds | Otariid Pinnipeds | Sea Turtles |
| **PTS SEL$_{cum}$** | **320.2** | 0 | 1.0 | 10.4 | 0 | **15.4** |
| **PTS Peak** | 38.9 | **13.6** | **268.3** | **43.7** | **10.6** | 10.6 |

[1] Using the 50-m shot interval provides more conservative distances than the 400-m shot interval.

### 2.1.3.2 Operational Phase

Marine mammals and sea turtles are known to occur in the proposed survey areas. 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. 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 protected species observers (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) for the high-energy surveys only; (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). As anticipated to be required by the IHA, we propose 2 PSOs to be on watch during daylight hours and 1 PSO monitoring PAM at all times (during high-energy surveys), with a likely total complement of up to 5 PSOs[2]. It is unlikely that concentrations of large whales would be encountered within the 160-dB isopleth, but if they were, they would be avoided.

Mitigation measures that would be adopted during the proposed surveys include (1) power-down procedures, (2) shut-down procedures, and (3) ramp-up procedures. These measures are proposed by L-DEO based on past experience and for consistency with the PEIS.

***Shut-down/Power-down Procedures*.**—The operating airgun(s) would be shut down if a marine mammal is seen within or approaching the EZs; however, shut downs would not be required for small dolphins that are likely to approach the vessel. A shut down occurs when all airgun activity is suspended.

For recent high-energy surveys, NMFS required PSOs to establish and monitor a 500-m EZ for shut downs for marine mammals and to monitor an additional 500-m buffer zone beyond the EZ. For high-energy surveys, NMFS recently required PSOs to establish and monitor a 150-m EZ for shut downs for sea turtles and to monitor an additional 150-m buffer zone beyond the EZ. Although Level A takes would not be anticipated for the 2 GI gun surveys, for other low-energy seismic surveys, NMFS required PSOs to establish and monitor a 100-m shut down EZ for marine mammals and a 200-m buffer zone beyond the EZ. For low-energy surveys, NMFS recently required PSOs to establish and monitor a 100-m EZ for shut downs for sea turtles and to monitor an additional 100-m buffer zone beyond the EZ.

Additionally, for the high-energy source, the array would be powered down if an ESA-listed seabird were observed diving or foraging within the 500-m EZ. A power down requires the reduction of the full array to a single 40-in$^3$ airgun such that the radius of the threshold zone is decreased to the extent that seabirds are no longer in or about to enter the EZ. A shut down would be implemented for any foraging/diving ESA-listed seabirds observed within the 100-m EZ of the single airgun. For the low-energy array, the GI airguns would be shut down for diving or foraging seabirds observed within a 100-m EZ. Following a shut down for a marine mammal, airgun activity would not resume until the animal has cleared the EZ. The marine mammal would be considered to have cleared the EZ if

- it is visually observed to have left the EZ, or
- it has not been seen within the EZ for 15 min in case of small odontocetes and pinnipeds, or
- it has not been seen within the zone for 30 min in the case of all other marine mammals.

The airgun array would be ramped up gradually after a shut down for marine mammals. For ESA-listed sea turtles or seabirds observed in the EZ, a shut down not requiring ramp-up (i.e., a “pause”) is to be implemented until the sea turtle or seabird is no longer observed in the EZ (i.e., 15 minutes). Ramp-up procedures are described below.

***Ramp-up Procedures*.**—A ramp-up procedure would be followed when the airgun array begins operating after a specified period without airgun operations (except for shutdowns for ESA-listed sea turtles and seabirds). It is proposed that, for the present surveys, this period would be 30 min, as long as PSOs have maintained constant visual and acoustic observations and no detections within the EZ have occurred. Ramp up would not occur if a marine mammal has not cleared the EZ as described earlier.

---

[2] PSOs would have access to standard monitoring equipment, including thermal imaging cameras (e.g., FLIR M324 Thermal Imaging system) for night-time ramp-ups. The PAM system would consist of a 230-meter steel reinforced tow cable with a detachable 25-meter hydrophone array. The arrays consisted of two LF hydrophones (10 Hz to 24 kHz), two MF hydrophones (200 Hz to 200 kHz), two HF hydrophone elements (2 kHz to 200 kHz) and a depth gauge (100m capacity) potted directly into the cable. Additional details may be found in the associated IHA application.

For the high-energy surveys, ramp up would begin with the smallest airgun in the array. Ramp-up would begin by activating a single airgun of the smallest volume in the array and shall continue in stages by doubling the number of active elements at the commencement of each stage, with each stage of approximately the same duration. Airguns would be added in a sequence such that the source level of the array would increase in steps not exceeding 6 dB per 5-min period. During ramp up, the PSOs would monitor the EZ, and if marine mammals are sighted, a shut down would be implemented, respectively, as though the full array were operational. During the high-energy surveys, ramp up would only commence at night or during poor visibility if the EZ has been monitored acoustically monitored with PAM for 30 min prior to the start of operations without any marine mammal detections during that period. The low-energy surveys would not use PAM, including during ramp up at night.

The proposed operational mitigation measures are standard for seismic cruises, per the PEIS. 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. During the high-energy surveys, one observer would conduct PAM during day- and night-time seismic operations. Monitoring and mitigation measures are also described in the IHA application. A monitoring report would be provided to NMFS, both the Permits and Conservation Division and the ESA Interagency Cooperation Division.

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 international (e.g., JNCC Guidelines) and 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 3). 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 3 provides a summary of the Proposed Action and the alternatives.

### 2.3.1 Alternative E1: Alternative Location

Earthquake and tsunami hazards associated with Puerto Rico can only be addressed by imaging structures across the Puerto Rico Trench and nearby regions. The locations of the profiles are chosen to sample crust characterized by contrasting properties such as obliquity on plate convergence orientation of abyssal hill fabric, and location of historic and recent seismic activity. The Puerto Rico Trench is associated with anomalous, and hitherto unexplained characteristics, such as the widest trench (below 6000 m) and the lowest gravity anomaly on Earth, and anomalous subsidence of the north coast of Puerto Rico.

TABLE 3. Summary of Proposed Action, Alternative Considered, and Alternatives Eliminated.

| Proposed Action | Description |
|---|---|
| Proposed Action: Conduct marine geophysical surveys and associated activities off Puerto Rico | Under this action, research activities are proposed to study Earth processes and would involve marine seismic surveys. Active seismic portions would be expected to take ~21 days, and 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., British Virgin Islands, and Dominican Republic. 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 that would provide new constraints for examining earthquake and tsunami hazards associated with Puerto Rico would not be collected, and 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 | Earthquake and tsunami hazards associated with Puerto Rico can only be addressed by imaging structures across the Puerto Rico Trench and nearby regions. The locations of the profiles are chosen to sample crust characterized by contrasting properties such as obliquity on plate convergence orientation of abyssal hill fabric, and location of historic and recent seismic activity. The Puerto Rico Trench is associated with anomalous, and hitherto unexplained characteristics, such as the widest trench (below 6,000 m) and the lowest gravity anomaly on Earth, and anomalous subsidence of the north coast of Puerto Rico. The data that would be collected would add to the comprehensive assessment of geohazards for the subduction zone off Puerto Rico, such as earthquakes and tsunamis, which could potentially also impact the U.S. east coast. The proposed science underwent the NSF merit review process, and the science, including the site location, was determined to be meritorious. Researchers from the USGS also determined the location for the low-energy surveys to optimize data collection for their geohazard studies. |
| 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. |

### 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).

# 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 marine activity has the potential to impact marine biological resources within the project area. Terrestrial biological resources are also briefly discussed, as land seismometers would be deployed as part of the Proposed Action. 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 areas.
- *Land Use*—The majority of activities are proposed to occur in the marine environment, with the exception of the temporary installation and retrieval of land seismometers. For installation of seismometers, small, isolated holes would be dug by hand to install the sensors in the ground; sites would be easily accessible and occur on previously disturbed land. After the experiment, the sensors would be removed, and the holes would be refilled in by hand. The PIs would work with collaborators to identify installation sites, in conjunction with local private landowners. Activities would be minimal and temporary; no changes to current land uses, or activities in the proposed survey areas would result from the proposed 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. Deployment and retrieval of land seismometers would involve minimal ground disturbance (See above "*Land Use*" for more details on land seismometers). The proposed activity would, therefore, 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*—Deployment and retrieval of small temporary land seismometers would involve minimal ground disturbance on previously disturbed land. The land seismometers would not impact or effect terrestrial biological resources. There would be no designated ESA critical habitat in deployment areas.
- *Visual Resources*—No visual resources would be expected to be negatively impacted as the proposed activities would be short-term. For the majority of time, the vessel would not be within the viewshed of the coast, and land-based seismometers would be temporary and mainly buried.

- *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. Although there are a number of shore-accessible SCUBA diving sites along the coast of Puerto Rico (see Section 3.9), the proposed activities would occur in water depths >100 m, outside the range for recreational SCUBA diving. However, SCUBA divers in shallower, nearshore areas could be exposed to increased sound levels. Other human activities in the area around the survey vessel would include fishing, other vessel traffic, and whale watching. However, no significant impacts on SCUBA diving, fishing, vessel traffic, or whale watching would be anticipated particularly because of the short duration of the proposed activities and majority of activities occurring farther offshore. Fishing and potential impacts to fishing are described in further detail in Sections III and IV, respectively. No other socioeconomic impacts would be anticipated as result of the proposed activities.

## 3.1 Oceanography

Puerto Rico is tropical with warm temperatures and is surrounded by an insular shelf composed of carbonate and terrigenous sands (Department of the Navy 2002). The shelf is quite flat and relatively narrow, with the southern portion reaching 21 km at its widest (Department of the Navy 2002). The southwestern portion of the insular shelf (La Parguera) extends ~4–5 n.mi, offshore and is shielded from easterly swells, yielding low wave energy and high transparency (García 1998). The transparency of the water on the insular shelf allows for optimal reef growth extending to depths of 80 m (García 1998; Schärer-Umpierre et al. 2014). Further, the reefs on the southern coast of Puerto Rico are not only more abundant but include offshore and fringing reefs which, due to their distance from nearshore river runoff and trade wind transport, are better developed (Department of the Navy 2002). Marine environments in southwestern Puerto Rico consist of extensive coral reefs, mangroves, and seagrass beds (Schärer-Umpierre et al. 2014). These habitats provide essential spawning and feeding grounds for various marine species (García 1998; Department of the Navy 2002; Schärer-Umpierre et al. 2014).

The surface or upper 100 m waters surrounding Puerto Rico are affected mainly by the north-easterly Trade Winds as well as the Caribbean and Antilles currents (Department of the Navy 2002). The Caribbean current is located south of Puerto Rico, while the Antilles current is located to the north and has a higher velocity; both currents flow westerly, driving the surface waters of the Caribbean Sea (Department of the Navy 2002). The mid-depth and bottom waters in this area are driven by density rather than wind and have colder temperatures due to the influx of water from subpolar regions of the Atlantic (Department of the Navy 2002). These differences in temperature, however, are not great enough to cause thermohaline, or vertical, circulation throughout the water column (Gordon 1967; Department of the Navy 2002). Sea surface water temperatures vary just 1°C seasonally (Department of the Navy 2002). While the Caribbean Sea is generally oligotrophic, waters within the survey areas support up to 360.5 mg $C/m^2$/day (Sea Around Us 2021). Primary production increases significantly in waters south of Puerto Rico throughout July as salinity decreases and chlorophyll a reaches its peak (Department of the Navy 2002).

## 3.2 Protected Areas

The Cartagena Convention is an international, legally binding agreement that protects sensitive areas, species, and biodiversity, and promotes the sustainable exploitation of marine resources in the Wider Caribbean Region (UNEP-CEP 2021a). Under the Convention, the Specially Protected Areas and Wildlife

(SPAW) protocol, protected areas include marine reserves and sanctuaries; marine protected areas (MPAs); natural, national, and marine parks; natural reserves; and lagoon ponds (CAR-SPAW-RAC 2021). The Convention on Biological Diversity (CBD) classifies biologically important oceanic areas around the world as Ecologically and Biologically Significant Areas (EBSAs) based on uniqueness and rarity; importance for life stages for marine species; importance for threatened, endangered, or declining species/habitats; vulnerability, fragility, sensitivity, or recovery rate; biological productivity and diversity; and naturalness (CBD 2021a). Marine conservation areas within 50 km of the proposed survey transect lines are provided in Table 4 (see also Fig. 1), and those within 15 km of the proposed transect lines are described below. None are located within the proposed survey areas. Excluded are proposed protected areas, as these do not have designated protection measures or finalized boundaries. Critical habitat for sea turtles is discussed in Section 3.4. In addition to marine conservation areas, some of the land seismometer stations are near wetlands or riverine habitats on Puerto Rico. One site is located within 25 m of a freshwater emergent wetland, and five sites are within 25 m of riverine habitat.

The Caja de Muertos Natural Reserve is a 12.7 km$^2$ area east of the northeastern portion of the proposed USGS transect lines, off south-central Puerto Rico (Aguilar-Perera et al. 2006). The reserve encompasses Caja de Muertos Island, Morrillito Island, Berberia Cay, and their associated marine benthic communities (NOAA 2009). This reserve protects sensitive seagrass and coral reef benthic habitats, along with nesting sites for sea turtles and seabirds (García et al. 2003; NOAA 2009; León-Pérez et al. 2020).

The La Parguera Natural Reserve is west of the northwestern portion of the proposed USGS seismic lines and extends 9 n.mi. into the Caribbean Sea from the southwestern Puerto Rican coast (NOAA 2009). Designated in 1979, this 32.7 km$^2$ reserve includes keys, mangrove islands, coastal mangroves and associated lagoons, salt marshes, extensive coral reefs, seagrass beds, and two bioluminescent bays, Habhia Fosforescente and Monsio Jose (Aguilar-Perera et al. 2006; MCI 2021; UNEP-CEP 2021b). This site permits fishing and does not otherwise restrict activities within its boundaries (MCI 2021).

The Guánica State Forest Natural Reserve encompasses a 54 km$^2$ area along the southwestern coast of Puerto Rico, north of the northwestern portion of the proposed USGS transect lines (Aguilar-Perera et al. 2006). This natural reserve was designated in 1985 to conserve marine habitats such as lagoons, mangroves, seagrass beds, and coral reefs, along with terrestrial forest habitat that hosts Puerto Rico's highest bird and plant biodiversity, including 48 endangered and 16 endemic plant species (NOAA 2009; Hall and Day 2014). For this reason, this natural reserve was also named a UNESCO Biosphere Reserve in 1981 (Hall and Day 2014).

The 15.5 km$^2$ Boquerón State Forest Natural Reserve is located along Puerto Rico's southwestern coastline and extends 9 n.mi. southwards from Cabo Rojo (Aguilar-Perera et al. 2006; NOAA 2009). This reserve was designated to protect ~135 bird species, including migratory birds and endemic/endangered avian species; wetlands; lagoons; Puerto Rico's largest west coast mangrove forest; and open marine ecosystems (NOAA 2009). Commercial fishing is restricted within the reserve in support of its conservation goals (Hernández et al. 2021; MCI 2021).

The southern ends of the proposed MCS-D4 and MCS-CN transect lines are adjacent to the Hacienda La Esperanza Natural Reserve MPA, off northern Puerto Rico. This reserve was designated in 1987 to address water quality issues with the goal of protecting habitat for migratory birds and nesting areas for leatherback, hawksbill, and green sea turtles (UNEP-CEP 2021b). There are currently no restrictions for activities within this reserve (MCI 2021).

TABLE 4. Protected areas within 50 km of the proposed survey transect lines in the Northwest Atlantic Ocean (Source: CAR-SPAW-RAC 2021; CBD 2021b; UNEP-CEP 2021b; UNEP-WCMC and IUCN 2021).

| **Designation** | **Name** | **Status** | **Managing Authority** | **Managing Country** | **Within 15 km** |
|---|---|---|---|---|---|
| Marine Mammal Sanctuary | Silver and Navidad Banks | D | NR | Dominican Republic | No |
| Marine Sanctuary | Southeast Reefs | D | NR | Dominican Republic | No |
| Marine Park | Virgin Gorda | P | National Parks Trust of the Virgin Islands/Conservation and Fisheries Department | Virgin Islands, UK | No |
| Landscape/ Seascape | Anegada West | P | National Parks Trust of the Virgin Islands | Virgin Islands, UK | No |
| Landscape/ Seascape | Anegada Island | P | National Parks Trust of the Virgin Islands/Conservation and Fisheries Department | Virgin Islands, UK | No |
| MPA | Caja de Muertos Natural Reserve | D | State and Fish Wildlife | Puerto Rico, US | Yes |
| MPA | Punta Guaniquilla Natural Reserve | D | State and Fish Wildlife | Puerto Rico, US | No |
| MPA | La Parguera Natural Reserve | D | State Fish and Wildlife / State Department of Natural Resources | Puerto Rico, US | Yes |
| MPA | Aguirre State Forest | D | State Fish and Wildlife / State Department of Natural Resources | Puerto Rico, US | No |
| MPA | Guánica State Forest Natural Reserve | D | State Fish and Wildlife / State Department of Natural Resources | Puerto Rico, US | Yes |
| MPA | Boquerón State Forest Natural Reserve | D | State and Fish Wildlife | Puerto Rico, US | Yes |
| MPA | Arrecifes de Tourmaline Natural Reserve | D | State and Fish Wildlife | Puerto Rico, US | No |
| MPA | Hacienda La Esperanza Natural Reserve | D | Non-Governmental Organization | Puerto Rico, US | Yes |
| MPA | Caño Tiburones Natural Reserve | D | State and Fish Wildlife | Puerto Rico, US | No |
| MPA | Cueva del Indio Natural Reserve | D | State Fish and Wildlife / State Department of Natural Resources | Puerto Rico, US | Yes |
| MPA | Laguna Joyuda Natural Reserve | D | State Fish and Wildlife / State Department of Natural Resources | Puerto Rico, US | No |
| MPA | Pantano Cibuco Natural Reserve | D | State Fish and Wildlife / State Department of Natural Resources | Puerto Rico, US | No |
| MPA | Punta Petrona Natural Reserve | D | State Fish and Wildlife / State Department of Natural Resources | Puerto Rico, US | No |
| EBSA | Marine Mammal Sanctuary Banco de la Plata y Banco de la Navidad *(Silver and Navidad Banks*) | D | Convention on Biological Diversity | | No |

EBSA = Ecologically or Biologically Significant Area; MPA = Marine Protected Area; Status: D = Designated, P = Proposed; UK = United Kingdom of Great Britain and Northern Ireland; US = United States.

The southern portion of proposed transect line MCS-D4 is adjacent to the northeastern tip of the Cueva del Indio Natural Reserve MPA, off the northern coast of Puerto Rico. This 15.6 km$^2$ reserve extends 9 n.mi. northwards of Puerto Rico and was designated to protect coral reefs and their associated benthic biota; coastal forests; sandy beaches; and cemented dunes, along with sea turtle nesting sites (Aguilar-Perera et al. 2006; NOAA 2009). Commercial fishing is not permitted within the reserve boundaries (MCI 2021).

## 3.3 Marine Mammals

According to Debrot et al. (2013), at least 33 marine mammal species have been documented in the Wider Caribbean Region (WCR). Mignucci-Gianonni (1998) reported 17 species of cetaceans for Puerto Rico and the Virgin Islands. The distribution and abundance of marine mammals in the northern Caribbean Sea are poorly known (Roden and Mullin 2000; Mignucci-Giannoni 1998). Twenty-eight species of cetaceans could occur within the proposed survey areas in the Northwest Atlantic Ocean, including six mysticetes (baleen whales) and 22 odontocetes (toothed whales) (Table 5); four of these marine mammals are listed as ***endangered*** under the ESA, including the sperm, blue, sei, and fin whales.

It is unlikely that Sowerby's beaked whales (*Mesoplodon bidens*), northern bottlenose whale (*Hyperoodon ampullatus*), North Atlantic right whales (*Eubalaena glacialis*), Atlantic white-sided dolphins (*Lagenorhynchus acutus*), white-beaked dolphins (*Lagenorhynchus albirostris*), and harbor porpoise (*Phocoena phocoena*) would be encountered. Additionally, pinniped occurrence in the Caribbean is extralimital and is not discussed further.

TABLE 5. The habitat, occurrence, population sizes, and conservation status of marine mammals that could occur in or near the proposed project area off Puerto Rico, Northwest Atlantic Ocean.

| | | | | | **Conservation Status** | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Species** | **Habitat** | **Occurrence in study area off Puerto Rico at time of surveys[1]** | **Abun-dance for Western North Atlantic[2]** | **Abun-dance for AFTT[3]** | **US ESA[4]** | **SPAW[5]** | **DR Red List[6]** | **IUCN[7]** | **CITES[8]** |
| ***Mysticetes*** | | | | | | | | | |
| Fin whale | Coastal, pelagic | Rare | 6,802 | 11,672 | E | II | - | VU | I |
| Blue whale | Pelagic | Rare | 402[10] | 191 | E | II | - | EN | |
| Sei whale | Pelagic | Rare | 6,292[11] | 19,530 | E | II | - | EN | |
| Bryde's whale | Pelagic & coastal | Rare | - | 536 | E | II | - | LC | I |
| Minke whale | Coastal waters | Uncommon | 21,968[12] | 13,784 | NL | II | - | LC | I |
| Humpback whale<br>*West Indies DPS* | Mainly nearshore & banks | Uncommon | 1,396[13] | 4,990 | NL | II | - | LC[9] | I |
| ***Odontocetes*** | | | | | | | | | |
| Sperm whale | Usually pelagic & deep seas | Common | 4,349[14] | 64,015 | E | II | - | VU | I |
| Pygmy sperm whale | Deeper waters off the shelf | Uncommon | 7,750[15] | 26,043[15] | NL | II | - | DD | II |
| Dwarf sperm whale | Deeper waters off the shelf | Uncommon | 7,750[15] | 26,043[15] | NL | II | - | DD | II |
| Cuvier's beaked whale | Pelagic | Uncommon | 5,744 | 65,069[17] | NL | II | - | LC | II |

| | | | | | Conservation Status | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Species** | **Habitat** | **Occurrence in study area off Puerto Rico at time of surveys[1]** | **Abun-dance for Western North Atlantic[2]** | **Abun-dance for AFTT[3]** | **US ESA[4]** | **SPAW[5]** | **DR Red List[6]** | **IUCN[7]** | **CITES[8]** |
| Gervais' beaked whale | Pelagic | Uncommon | 10,107[16] | 65,069[17] | NL | II | - | DD | II |
| Blainville's beaked whale | Pelagic | Uncommon | 10,107[16] | 65,069[17] | NL | II | - | DD | II |
| True's beaked whale | Pelagic | Rare | 10,107[16] | 65,069[17] | NL | II | - | LC | II |
| Rough-toothed dolphin | Mostly pelagic | Common | 136 | 32,848 | NL | II | - | LC | II |
| Bottlenose dolphin | Continental Shelf, coastal & offshore | Common | 62,851[18]<br>7,462[19] | 418,151 | NL | II | VU | LC | II |
| Pantropical spotted dolphin | Mainly pelagic | Common | 6,593 | 321,740 | NL | II | - | LC | II |
| Atlantic spotted dolphin | Mainly coastal waters | Common | 39,921 | 259,519 | NL | II | - | LC | II |
| Spinner dolphin | Coastal, pelagic | Common | 4,102 | 152,511 | NL | II | - | LC | II |
| Clymene dolphin | Pelagic | Uncommon | 4,237 | 181,209 | NL | II | - | LC | II |
| Striped dolphin | Off the continental shelf | Common | 67,036 | 412,729 | NL | II | - | LC | II |
| Fraser's dolphin | Water >1000 m | Uncommon | - | 19,585 | NL | II | - | LC | II |
| Common dolphin | Shelf, pelagic | Common | 172,974 | 473,260 | NL | II | - | LC | II |
| Risso's dolphin | Waters 400-1000 m | Common | 35,215 | 78,205 | NL | II | - | LC | II |
| Melon-headed whale | Oceanic | Common | - | 64,114 | NL | II | - | LC | II |
| Pygmy killer whale | Oceanic | Uncommon | - | 9,001 | NL | II | - | LC | II |
| False killer whale | Pelagic | Uncommon | 1,791 | 12,682 | NL | II | - | NT | II |
| Killer whale | Widely distributed | Uncommon | - | 972 | NL | II | - | DD | II |
| Short-finned pilot whale | Mostly pelagic | Common | 28,924 | 264,907[20] | NL | II | - | LC | II |

- not available. DR = Dominican Republic. [1] Occurrence in area at the time of the surveys; based on professional opinion and available data. [2] Abundance estimates for the U.S. Atlantic (Hayes et al. 2022; NMFS 2022); no abundance estimates are available for the Puerto Rico/U.S. Virgin Islands stock. [3] Abundance estimates for the Atlantic Fleet Testing and Training (AFTT) Area, including the Gulf of Mexico, from Roberts et al. (2023). [4] U.S. Endangered Species Act: E = endangered, NL = not listed. [5] Specially Protected Areas and Wildlife Protocol of the Cartagena Convention: Annex II, strictly protected fauna. Accessed at https://www.unep.org/cep/what-we-do/specially-protected-areas-and-wildlife-spaw. [6] Lista de Especies en Peligro de Extinción, Amenzadaso Protegidas de la República Dominicana, List Roja (Ministro de Medio Ambiente y Recursos Naturales 2011): VU = Vulnerable (risk of extinction in the médium term). [7] International Union for the Conservation of Nature Red List of Threatened Species version 2021-1: VU = vulnerable; NT = near threatened; LC = least concern; DD = data deficient. [8] Convention on International Trade in Endangered Species of Wild Fauna and Flora: Appendix I = Threatened with extinction; Appendix II = not necessarily now threatened with extinction but may become so unless trade is closely controlled. [9] Global status. [10] Minimum population size. [11] Nova Scotia. [12] Canadian East Coast. [13] Gulf of Maine. [14] North Atlantic. [15] Estimate includes dwarf and pygmy sperm whales. [16] Estimate includes all Mesoplodont whales in the North Atlantic, including Sowerby's beaked whale. [17] Beaked whale guild. [18] Offshore stock. [19] Oceanic stock. [20] Pilot whale guild.

The Antillean manatee (*Trichechus manatus manatus*) is known to occur in the WCR and occurs in nearshore waters (<20 m deep) of the Dominican Republic (Tejo 2021) and Puerto Rico (e.g., Drew et al. 2012; Hunter et al. 2012); however, some individuals are known to travel in water depths <100 m (Drew et al. 2012). None of the survey effort would occur in shallow water (<100 m), and no manatees along the coast of Puerto Rico would be exposed to sound levels >160 dB. The closest survey lines are at least 42 km from Dominican Republic, 68 km for the U.S. Virgin Islands, and 13 km from the British Virgin Islands. However, manatees do not typically occur in the Virgin Islands, although a few sightings have been made (USFWS 2007). Pinniped occurrence in the Caribbean is extralimital and is not discussed further.

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. The Caribbean Sea detailed analysis area (DAA), as defined in the PEIS, is located just south of the proposed survey areas; The Northwestern Atlantic DAA is located northeast of the proposed survey areas. General information on the taxonomy, ecology, distribution and movements, and acoustic capabilities of baleen whales and toothed whales are given in § 3.6.1 and § 3.7.1, respectively, of the PEIS.

## 3.3.1 Mysticetes

### 3.3.1.1 Humpback Whale (*Megaptera novaeangliae*)

The humpback whale is found throughout all oceans of the World (Clapham 2018). Based on genetic data, there could be three subspecies occurring in the North Pacific, North Atlantic, and Southern Hemisphere (Jackson et al. 2014). It is highly migratory, undertaking one of the world’s longest mammalian migrations by traveling between mid- to high-latitude waters where it feeds during spring to fall and low-latitude wintering grounds over shallow banks, where it mates and calves (Winn and Reichley 1985; Bettridge et al. 2015). Although considered to be mainly a coastal species, humpback whales often traverse deep pelagic areas while migrating (Calambokidis et al. 2001; Garrigue et al. 2002, 2015; Zerbini et al. 2011).

In the western North Atlantic, the humpback whale occurs from Greenland to Venezuela (Würsig et al. 2000). For most North Atlantic humpbacks, the summer feeding grounds range from the northeast coast of the U.S. to the Barents Sea (Katona and Beard 1990; Smith et al. 1999). In the winter, the majority of humpback whales migrate to wintering areas in the West Indies (Smith et al. 1999); this is known as the West Indies Distinct Population Segment (DPS) (Bettridge et al. 2015). Feeding areas have no DPS status (Bettridge et al. 2015; NMFS 2016a). According to Hayes et al. (2020), NMFS is currently reviewing the global humpback whale stock structure in light of the revisions to their ESA listing and identification of 14 DPSs (e.g., NMFS 2016b). The West Indies DPS population is estimated at 10,852 individuals (Stevick et al. 2003a).

Stevick et al. (2018) found that the timing and migration destinations of humpback whales in the northwestern and southeastern Caribbean are different and suggested that there could be two different breeding populations in the West Indies. Stevick et al. (2003b) reported that males were often seen on breeding grounds earlier than females. Some individuals from the North Atlantic are known to migrate to Cape Verde to breed (e.g., Wenzel et al. 2009). A small proportion of the Atlantic humpback whale population remains in high latitudes in the eastern North Atlantic during winter (e.g., Christensen et al. 1992).

The largest winter concentration of humpbacks occurs at Silver and Navidad Banks off northeastern Dominican Republic (Mattila et al. 1989; Whitehead and Moore 1992). Hundreds of humpbacks aggregate there from January through March to calve (Mattila et al. 1989). Mona Passage (Puerto Rico), Virgin Bank, and Anguilla Bank are also considered to be major calving grounds (Mattila and Clapham 1989). Humpback whales are commonly sighted in Puerto Rico and the Virgin Islands during the winter (Mignucci-Giannoni 1998). Hotspots for humpback whales off the west coast of Puerto Rico are related to bathymetry, with groups of two or more primarily occurring in deeper water, singing males occur near the shelf edge, whereas non-singing individuals occur farther from the shelf edge; mother-calf pairs primarily occur in shallow water, unless they are with an escort, in which case they were seen farther from shore (MacKay et al. 2016). Similarly, Sanders et al. (2005) reported that mother-calf pairs sighted off northwestern Puerto Rico from January–March were most frequently reported in shallow water <100 m deep.

Samaná Bay, on the northeastern coast of the Dominican Republic, is also recognized as an important winter ground for western North Atlantic humpback whales (Mattila et al. 1994; Betancourt et al. 2012). Photo identification has shown that whales that occurred in the Dominican Republic were seen at high-latitude feeding areas, such as the Gulf of Maine, Newfoundland, Gulf of St. Lawrence, and Greenland), as well as at other regions in the West Indies, such as Silver Bank and Navidad Bank off Dominican Republic, Puerto Rico, Guadeloupe, Virgin Bank, and Anguilla Bank (Mattila et al. 1989, 1994; MacKay et al. 2019), even within the same season (e.g., MacKay et al. 2019). Two humpbacks outfitted with satellite transmitters near the Dominican Republic during winter and spring of 2008–2012 were later reported off the east coast of Canada (Kennedy et al. 2014). Humpback whale vocalizations were recorded off the northern Dominican Republic during each month from December 2016 through May 2017 (Heenehan et al. 2019). Humpback whales were sighted within the proposed survey areas during winter 1995 (Roden and Mullin 2000), winter 2000 (Swartz et al. 2001), and winter 2001 (Swartz et al. 2002); they were also detected there acoustically during winter 2001 (Swartz et al. 2002). Although most sightings of humpbacks occur off the northern Dominican Republic, four sightings were made during March 2005 off the southern coast (Whaley et al. 2006). There are numerous records of humpbacks throughout the proposed study area, including sightings in offshore waters to the north of Puerto Rico, nearshore sightings off western Puerto Rico and around the Virgin Islands, and numerous sightings on Silver and Navidad banks north of the Dominican Republic; all sightings were reported for January–March (OBIS 2021). However, some sightings have been reported in nearshore waters of northern Puerto Rico and the U.S. Virgin Islands during fall (DoN 2002).

#### 3.3.1.2 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/summer and southward migration in autumn (Stewart and Leatherwood 1985). There are four recognized minke whale populations in the North Atlantic largely based on feeding grounds: Canadian east coast, west Greenland, central North Atlantic, and northeast Atlantic (Donovan 1991). Although some minke whale populations have been well studied on summer feeding grounds, information on wintering areas and migration routes is lacking (Risch et al. 2014).

Minke whales occur in the southeastern U.S. and Caribbean during the winter; however, a lack of acoustic detection in the region during summer indicates either absence of minke whales at that time of year, or a change in vocal behavior at different times of the year (Risch et al. 2014). Risch et al. (2014) deployed acoustic detectors throughout the North Atlantic to detect minke whale occurrence; one recorder was deployed in the Caribbean, at Saba Bank. There, minke whales were acoustically detected during winter and spring (Risch et al. 2014). Minke whale vocalizations were also recorded 200–350 km off northeastern Puerto Rico, March 1994 (Mellinger et al. 2000). Mignucci-Giannoni (1998) reported three sightings for Puerto Rico and the Virgin Islands up to 1989. One minke whale was sighted in the proposed survey area north of Puerto Rico during winter 1995 (Roden and Mullin 2000). Another sighting of a minke was made in offshore waters of the proposed survey area north of Puerto Rico on 20 January 2014 (Rodriguez-Ferrer et al. 2018). In the OBIS database, there are 16 records of minke whales for the northeastern portion of the proposed survey area; all sightings were reported during March 1994 (OBIS 2021).

#### 3.3.1.3 Bryde's Whale (*Balaenoptera edeni/brydei*)

Bryde's whale occurs in all tropical and warm temperate waters in the Pacific, Atlantic, and Indian oceans, between 40°N and 40°S (Kato and Perrin 2018). It is one of the least known large baleen whales, and it remains uncertain how many species are represented in this complex (Kato and Perrin 2018). *B. brydei* is commonly used to refer to the larger form or "true" Bryde's whale and *B. edeni* to the smaller form; however, some authors apply the name *B. edeni* to both forms (Kato and Perrin 2018). Bryde's whale remains in warm (>16°C) water year-round, although seasonal movements have been recorded towards the Equator in winter and offshore in summer (Kato and Perrin 2018). However, Debrot (1998) noted that this species is sedentary in the tropics. Bryde's whales are known to occur in both shallow coastal and deeper offshore waters (Jefferson et al. 2015). It does not undertake long north/south migrations, although local seasonal movements toward the Equator in winter and to higher latitudes in summer take place in some areas (Evans 1987; Jefferson et al. 2015). One stranding has also been reported for the U.S. Virgin Islands (Mignucci-Giannoni 1996; Mignucci-Giannoni et al. 1999a). Erdman (1970 *in* Ward et al. 2001) reported sightings for Puerto Rico and the Virgin Islands. There are no sightings in the OBIS database for the proposed survey areas or in the Caribbean Sea (OBIS 2021).

#### 3.3.1.4 Sei Whale (*Balaenoptera borealis*)

The sei whale occurs in all ocean basins (Horwood 2018) but appears to prefer mid-latitude temperate waters (Jefferson et al. 2015). It undertakes seasonal migrations to feed in subpolar latitudes during summer and returns to lower latitudes during winter to calve (Horwood 2018). On summer feeding grounds, sei whales associate with oceanic frontal systems (Horwood 1987). The sei whale is pelagic and generally not found in coastal waters (Harwood and Wilson 2001). It occurs 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). Sei whales migrate from temperate zones occupied in winter to higher latitudes in the summer, where most feeding takes place (Gambell 1985). A small number of individuals have been sighted in the eastern North Atlantic between October and December, indicating that some animals may remain at higher latitudes during winter (Evans 1992). Sei whales have been seen from South Carolina south into the Gulf of Mexico and the Caribbean during winter (Rice 1998); however, the location of sei whale wintering grounds in the North Atlantic is unknown (Víkingsson et al. 2010). There are three sei whale stocks in the North Atlantic: Nova Scotia, Iceland-Denmark Strait, and Eastern (Donovan 1991). Mignucci-Giannoni (1998) reported two sightings for Puerto Rico and the Virgin Islands. There has also been a stranding in the Dominican Republic (Whitt et al. 2011). There are no sightings in the OBIS database for the proposed survey areas or in the Caribbean Sea (OBIS 2021).

#### 3.3.1.5 Fin Whale (*Balaenoptera physalus*)

The fin whale is widely distributed in all the World's oceans (Gambell 1985), although it is most abundant in temperate and cold waters (Aguilar and García-Vernet 2018). Nonetheless, its overall range and distribution are not well known (Jefferson et al. 2015). A review of fin whale distribution in the North

Pacific noted the lack of sightings across pelagic waters between eastern and western winter areas (Mizroch et al. 2009). Fin whales most commonly occur offshore but can also be found in coastal areas (Jefferson et al. 2015).

Most populations migrate seasonally between temperate waters where mating and calving occur in winter, and polar waters where feeding occurs in summer (Aguilar and García-Vernet 2018). Some animals may remain at high latitudes in winter or low latitudes in summer (Edwards et al. 2015). The northern and southern fin whale populations likely do not interact owing to their alternate seasonal migration; the resulting genetic isolation has led to the recognition of two subspecies, *B. physalus quoyi* and *B. p. physalus* in the Southern and Northern hemispheres, respectively (Anguilar and García-Vernet 2018). The fin whale is known to use the shelf edge as a migration route (Evans 1987). Sergeant (1977) suggested that fin whales tend to follow steep slope contours, either because they detect them readily, or because the contours are areas of high biological productivity. However, fin whale movements have been reported to be complex (Jefferson et al. 2015).

In the North Atlantic, fin whales are found in summer from Baffin Bay, Spitsbergen, and the Barents Sea, south to North Carolina and the coast of Portugal (Rice 1998). In winter, they have been sighted from Newfoundland to the Gulf of Mexico and the Caribbean, and from the Faroes and Norway south to the Canary Islands (Rice 1998). Based on geographic differences in fin whale calls, Delarue et al. (2014) suggested that there are four distinct stocks in the Northwest Atlantic, including a central North Atlantic stock that and extends south along the Mid-Atlantic Ridge. Similarly, the four stocks in the Northwest Atlantic currently recognized by the North Atlantic Marine Mammal Commission (NAMMCO 2016) are located off West Iceland (in the Central Atlantic), Eastern Greenland, Western Greenland, and Eastern Canada. Mignucci-Giannoni (1998) reported three sightings for Puerto Rico and the Virgin Islands. Edwards et al. (2015) reported no detections for fin whales in the Caribbean Sea or north of Puerto Rico. There is one record of a fin whale in the OBIS database in the northern portion of the survey area; the sighting was made in February 1978; there are no other records for the Caribbean Sea (OBIS 2021).

#### 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). 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). Blue whales are most often found in cool, productive waters where upwelling occurs (Reilly and Thayer 1990). Generally, blue whales are seasonal migrants between high latitudes in summer, where they feed, and low latitudes in winter, where they mate and give birth (Lockyer and Brown 1981). Their summer range in the North Atlantic extends from Davis Strait, Denmark Strait, and the waters north of Svalbard and the Barents Sea, south to the Gulf of St. Lawrence and the Bay of Biscay (Rice 1998). Although the winter range is mostly unknown, some occur near Cape Verde at that time of year (Rice 1998). Mignucci-Giannoni (1998) noted that blue whales may not occur regularly in the Caribbean, as there is a single record for Panama. There are no sightings in the OBIS database for the proposed survey areas or in the Caribbean Sea (OBIS 2021).

### 3.3.2 Odontocetes

#### 3.3.2.1 Sperm Whale (*Physeter macrocephalus*)

The sperm whale is widely distributed, occurring from the edge of the polar pack ice to the Equator in both hemispheres, with the sexes occupying different distributions (Whitehead 2018). In general, it is distributed over large temperate and tropical areas that have high secondary productivity and steep underwater topography, such as volcanic islands (Jaquet and Whitehead 1996). Its distribution and relative abundance can vary in response to prey availability, most notably squid (Jaquet and Gendron 2002). Females generally inhabit waters >1000 m deep at latitudes <40º where sea surface temperatures are <15ºC; adult males move to higher latitudes as they grow older and larger in size, returning to warm-water breeding grounds (Whitehead 2018). Sperm whales are the second most frequently sighted large cetacean in the northeastern Caribbean (Roden and Mullin 2000). Mignucci-Giannoni (1998) reported 43 sightings for Puerto Rico and the Virgin Islands up to 1989; most occurred near the shelf edge. Some sightings have been reported during the fall (DoN 2002). Rodriguez-Ferrer et al. (2018) reported several other sightings along the shelf edge off western Puerto Rico between 1995 and 2018. Sperm whales were also seen south of the U.S. Virgin Islands during winter 1995 (Roden and Mullin 2000), and they were detected visually and acoustically in the EEZ of Puerto Rico, and the U.S. and British Virgin Islands during winter 2001 (Swartz et al. 2002). Opportunistic sightings of sperm whales have also been reported for the Dominican Republic (Whaley et al. 2006). There are 11 records in the OBIS database within or near the proposed survey areas (OBIS 2021).

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

Pygmy and dwarf sperm whales are distributed widely throughout tropical and temperate seas, but their precise distributions are unknown because much of what we know of the species comes from strandings (McAlpine 2018). It has 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). *Kogia* spp. are difficult to sight at sea, because of their dive behavior and perhaps because of their avoidance reactions to ships and behavior changes in relation to survey aircraft (Würsig et al. 1998). When they are observed, both *Kogia* species are found primarily along the continental shelf edge and slope and over deeper waters off the shelf (Hansen et al. 1994; Davis et al. 1998; Jefferson et al. 2015). However, McAlpine (2018) noted that dwarf sperm whales may be more pelagic than pygmy sperm whales. Although there are few useful estimates of abundance for pygmy or dwarf sperm whales anywhere in their range, they are thought to be fairly common in some areas.

In the western North Atlantic, pygmy sperm whales are known to occur from Nova Scotia to Cuba, and dwarf sperm whales are distributed from Virginia to the Caribbean (Würsig et al. 2000; Würsig 2017). Records for the Caribbean are uncommon, but several strandings have been reported for the Dominican Republic, Puerto Rico, and the Virgin Islands (Cardona-Maldonado and Mignucci-Giannoni 1999). Several strandings of both *Kogia* spp. have been recorded in Puerto Rico, only pygmy sperm whale strandings have reported for the U.S. Virgin Islands, and strandings of undetermined *Kogia* sp. have been recorded for the Dominican Republic (Mignucci-Giannoni 1996, 1998; Mignucci-Giannoni et al. 1999a; Cardona-Maldonado and Mignucci-Giannoni 1999). There is one record of a dwarf sperm whale and one of an unidentified *Kogia* sp. in the OBIS database within the proposed survey areas, just off the northern coast of Puerto Rico; there are several other records of unidentified *Kogia* sp. for the Virgin Islands and one record of a pygmy sperm whale off Anguilla (OBIS 2021).

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

Cuvier's beaked whale is probably the most widespread and common of the beaked whales, although it is not found in high-latitude polar waters (Heyning 1989; Baird 2018a). It is rarely observed at sea and is known mostly from strandings; it strands more commonly than any other beaked whale (Heyning 1989). Cuvier's beaked whale is found in deep water in the open ocean and over and near the continental slope (Gannier and Epinat 2008; Baird 2018a). It is rarely found close to mainland shores, except in submarine canyons or in areas where the continental shelf is narrow and coastal waters are deep (Carwardine 1995). Its inconspicuous blows, deep-diving behavior, and tendency to avoid vessels all help to explain the infrequent sightings (Barlow and Gisiner 2006).

In the western North Atlantic, these whales occur from Massachusetts to Florida, the West Indies, and the Gulf of Mexico (Würsig et al. 2000). Strandings are common in Puerto Rico and the Virgin Islands, with most records in winter and spring (Mignucci-Giannoni 1996, 1998; Mignucci-Giannoni et al. 1999a). Several sightings have also been made, including north and south of Puerto Rico (DoN 2002). There is one record southwest of Anguilla in the OBIS database (OBIS 2021).

### 3.3.2.4 Gervais' Beaked Whale (*Mesoplodon europaeus*)

Although Gervais' beaked whale is generally considered to be a North Atlantic species, it likely occurs in deep waters of the temperate and tropical Atlantic Ocean in both the northern and southern hemispheres (Jefferson et al. 2015). Its distribution is primarily known from stranding records. Strandings may be associated with calving, which takes place in shallow water (Würsig et al. 2000). Gervais' beaked whale usually inhabits deep waters (Davis et al. 1998). It is more frequent in the western than the eastern Atlantic (Mead 1989) and occurs from New York to Florida and the GoM (Rice 1998). Numerous sightings and strandings have been reported for the Caribbean, including in the Dominican Republic and the U.S. Virgin Islands (Mignucci-Giannoni 1996; Mignucci-Giannoni et al. 1999a; Rosario-Delestre et al. 1999). There is one record just off the southeastern Puerto Rico shoreline in the OBIS database (OBIS 2021).

### 3.3.2.5 Blainville's Beaked Whale (*Mesoplodon densirostris*)

Blainville's beaked whale is found in tropical and warm temperate waters of all oceans; it has the widest distribution throughout the world of any *Mesoplodon* species (Pitman 2018). Occasional occurrences in cooler, higher-latitude waters are presumably related to warm-water incursions (Reeves et al. 2002). It is rarely sighted, and most of the knowledge on the distribution of this species is derived from stranding data. There is no evidence that Blainville's beaked whales undergo seasonal migrations, although movements into higher latitudes are likely related to warm currents, such as the Gulf Stream in the North Atlantic. Like other beaked whales, Blainville's beaked whale is generally found in waters 200–1400 m deep (Gannier 2000; Jefferson et al. 2015). However, it may also occur in coastal areas, particularly where deep-water gullies come close to shore.

In the western North Atlantic, it is found from Nova Scotia to Florida, the Bahamas, and the GoM (Würsig et al. 2000). Two sightings have been made in the Caribbean – one each at Grand Cayman Island and Puerto Rico (Rosario-Delestre et al. 1999). One stranding has been reported for Puerto Rico (Mignucci-Giannoni 1996; Mignucci-Giannoni et al. 1999a). There is one record between the U.S. and British Virgin Islands in the OBIS database (OBIS 2021).

### 3.3.2.6 True's Beaked Whale (*Mesoplodon mirus*)

True's beaked whale is mainly oceanic and occurs in warm temperate waters of the North Atlantic and southern Indian oceans (Pitman 2018). In the western North Atlantic, strandings have been recorded from Nova Scotia (~46°N) to Florida (~27°N; MacLeod et al. 2005). There are no OBIS sightings of True's beaked whale near the proposed project area (OBIS 2021). True's beaked whale likely would be rare in the proposed project area, although Mignucci-Giannoni (1996, 1998) noted that it could occur in the Caribbean.

### 3.3.2.7 Rough-toothed Dolphin (*Steno bredanensis*)

The rough-toothed dolphin is distributed worldwide in tropical to warm temperate oceanic waters (Miyazaki and Perrin 1994). It generally occurs in deep, oceanic waters, but can be found in shallower coastal waters in some regions (Jefferson et al. 2015). In the western Atlantic, this species occurs between the southeastern U.S. and southern Brazil (Jefferson et al. 2015). Mignucci-Giannoni (1998) reported nine sightings for Puerto Rico and the Virgin Islands up to 1989, and Mignucci-Giannoni (1996) and Mignucci-Giannoni et al. (1999a) reported several strandings for Puerto Rico and the U.S. Virgin Islands. Swartz et al. (2002) reported one sighting of three individuals northeast of Puerto Rico during winter 2001 surveys. Rodriguez-Ferrer et al. (2018) reported another four sightings along the shelf edge off southwestern Puerto Rico between 2010 and 2017. There is one record off the east coast of Puerto Rico in the OBIS database (OBIS 2021).

### 3.3.2.8 Common Bottlenose Dolphin (*Tursiops truncatus*)

The bottlenose dolphin occurs in tropical, subtropical, and temperate waters throughout the world (Wells and Scott 2018). Although it is more commonly found in coastal and shelf waters, it can also occur in deep offshore waters (Jefferson et al. 2015). In the Northwest Atlantic, these dolphins occur from Nova Scotia to Florida, the GoM, and the Caribbean and southward to Brazil (Würsig et al. 2000). There are two distinct bottlenose dolphin types: a shallow water type mainly found in coastal waters and a deepwater type mainly found in oceanic waters (Duffield et al. 1983; Walker et al. 1999). The nearshore dolphins usually inhabit shallow waters along the continental shelf and upper slope, at depths <200 m (Davis et al. 1998, 2002). Klatsky (2004) noted that offshore dolphins show a preference for water <2186 m deep. As well as inhabiting different areas, these ecotypes differ in their diving abilities (Klatsky 2004) and prey types (Mead and Potter 1995). 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 2018). It is the most frequently sighted dolphin in Puerto Rico and the Virgin Islands (Mignucci-Giannoni 1998). Two sightings of bottlenose dolphins were made during winter 2001 off southern Puerto Rico and north of the Virgin Islands (Swartz et al. 2002). Bottlenose dolphins have also been seen during surveys of eastern Dominican Republic (Mattila et al. 1994; Whaley et al. 2006). There are eight records within or near the proposed survey areas in the OBIS database (OBIS 2021).

### 3.3.2.9 Pantropical Spotted Dolphin (*Stenella attenuata*)

The pantropical spotted dolphin is distributed worldwide in tropical and some subtropical waters, between ~40°N and 40°S (Jefferson et al. 2015). It is one of the most abundant cetaceans and is found in coastal, shelf, slope, and deep waters (Perrin 2018a). In the Northwest Atlantic, it occurs from North Carolina to the West Indies and down to the equator (Würsig et al. 2000). Pantropical spotted dolphins have been cited throughout the WCR, including off the Dominican Republic and off the northern and southern coasts of Puerto Rico (Jefferson and Lynn 1994; DoN 2002; Roden and Mullin 2000; Swartz et al. 2002; Mignucci-Giannoni et al. 2003; Whaley et al. 2006). There is one record off the southern coast of Puerto Rico in the OBIS database (OBIS 2021).

### 3.3.2.10 Atlantic Spotted Dolphin (*Stenella frontalis*)

The pantropical spotted dolphin is one of the most abundant cetaceans and is distributed worldwide in tropical and some subtropical waters, between ~40°N and 40°S (Jefferson et al. 2015). In the North Atlantic, it occurs from Brazil to New England and to the coast of Africa (Jefferson et al. 2015). There are two forms of Atlantic spotted dolphin—a large, heavily spotted coastal form that is usually found in shelf waters, and a smaller and less-spotted offshore form that occurs in pelagic offshore waters and around oceanic islands (Jefferson et al. 2015). In the western Atlantic, the distribution extends from southern New England, south to the Gulf of Mexico, and the Caribbean to Venezuela (Leatherwood et al. 1976; Perrin et al. 1994a; Rice 1998). The Atlantic spotted dolphin is common on the shelf off Puerto Rico and the Virgin Islands (Mignucci-Giannoni 1998; Debrot et al. 2013), as well as in deeper water north and south of Puerto Rico (Swartz et al. 2002). Rodriguez-Ferrer et al. (2018) reported numerous sightings along the shelf edge of Puerto Rico, in particular along the southwestern coast. Atlantic spotted dolphins have been sighted in coast waters of the Dominican Republic (e.g., Mattila et al. 1994; Whaley et al. 2006) as well as in offshore waters north of the Dominican Republic (Jefferson and Lynn 1994). There are seven records within or near the proposed survey areas in the OBIS database (OBIS 2021).

#### 3.3.2.11 Spinner Dolphin (*Stenella longirostris*)

The spinner dolphin is pantropical in distribution, including oceanic tropical and sub-tropical waters between 40ºN and 40ºS (Jefferson et al. 2015). It is generally considered a pelagic species, but it can also be found in coastal waters (Perrin 2018b). It is generally considered a pelagic species (Perrin 2018b) but can also be found in coastal waters and around oceanic islands (Rice 1998). In the western North Atlantic, it occurs from South Carolina to Florida, the Caribbean, GoM, and southward to Venezuela (Würsig et al. 2000). Mignucci-Giannoni (1998) reported 41 sightings for Puerto Rico and the Virgin Islands up to 1989. Rodriguez-Ferrer et al. (2018) reported 18 sightings off western Puerto Rico between 1995 and 2014. During February–March 2001 surveys off Puerto Rico, one sighting was made off the west coast and another was made off the north coast. DoN (2002) reported concentrations of spinner dolphins within the 1000-m isobath surrounding Puerto Rico and the Virgin Islands. There is one record off the southwestern coast of Puerto Rico in the OBIS database (OBIS 2021).

#### 3.3.2.12 Striped Dolphin (*Stenella coeruleoalba*)

The striped dolphin has a cosmopolitan distribution in tropical to warm temperate waters from ~50°N to 40°S (Perrin et al. 1994b; Jefferson et al. 2015). It is typically found in waters outside the continental shelf and is often associated with convergence zones and areas of upwelling; however, it has also been observed approaching shore where there is deep water close to the coast (Jefferson et al. 2015). In the Northwest Atlantic, it occurs from Nova Scotia to the Gulf of Mexico and south to Brazil (Würsig et al. 2000). Mignucci-Giannoni (1996, 1998) and Mignucci-Giannoni et al. (1999a) reported one stranding record for the Virgin Islands. A group of 140 striped dolphins was seen within the proposed survey area north of Puerto Rico during winter 1995 (Roden and Mullin 2000). There is one record in the northern portion of the proposed survey area in the OBIS database (OBIS 2021).

#### 3.3.2.13 Clymene Dolphin (*Stenella clymene*)

The Clymene dolphin only occurs in tropical and subtropical waters of the Atlantic Ocean (Jefferson et al. 2015). It inhabits areas where water depths are 700–4500 m or deeper (Fertl et al. 2003). However, there are a few records in water as shallow as 44 m (Fertl et al. 2003). In the western Atlantic, it occurs from New Jersey to Florida, the Caribbean Sea, the GoM, and south to Venezuela and Brazil (Würsig et al. 2000; Fertl et al. 2003). Mignucci-Giannoni (1996) did not report any strandings for Puerto Rico, but one stranding for Dominica.

#### 3.3.2.14 Risso's Dolphin (*Grampus griseus*)

Risso's dolphin is distributed worldwide in mid-temperate and tropical oceans (Kruse et al. 1999). although it shows a preference for mid-temperate waters of the shelf and slope between 30° and 45° (Jefferson et al. 2014). Although it occurs from coastal to deep water (~200–1000 m depth), it shows a strong preference for mid-temperate waters of upper continental slopes and steep shelf-edge areas (Hartman 2018). In the western Atlantic, this species is distributed from Newfoundland to Brazil (Kruse et al. 1999). Two sightings have been reported for the Virgin Islands (Mignucci-Giannoni 1998; DoN 2002), and three strandings have been reported for Puerto Rico (Mignucci-Giannoni 1996; Mignucci-Giannoni et al. 1999a; DoN 2002). There is one record just off the southwest coast of Puerto Rico in the OBIS database (OBIS 2021).

#### 3.3.2.15 Common Dolphin (*Delphinus delphis*)

The common dolphin is distributed in tropical to cool temperate waters of the Atlantic and the Pacific oceans from 60ºN to ~50ºS (Jefferson et al. 2015). It is common in coastal waters 200–300 m deep (Evans 1994), but it can also occur thousands of kilometers offshore (Jefferson et al. 2015). It appears to have a preference for areas with upwelling and steep sea-floor relief (Doksæter et al. 2008; Jefferson et al. 2015). Although it occurs off the U.S. east coast as far south as Florida (Perrin 2018c), its occurrence and distribution in the Caribbean are less well known (see Jefferson et al. 2009). There are no records of this species for the proposed survey areas in the OBIS database (OBIS 2021).

#### 3.3.2.16 Fraser's Dolphin (*Lagenodelphis hosei*)

Fraser's dolphin is a tropical oceanic species distributed between 30°N and 30°S that generally inhabits deep oceanic water (Dolar 2018). It ranges from the Gulf of Mexico to Uruguay in the western Atlantic (Rice 1998). However, Mignucci-Giannoni et al. (1999b) noted that there were only seven records for the Caribbean, including two strandings in Puerto Rico. DoN (2002) reported one additional strandings for Puerto Rico. The other records are for St. Vincent and Dominica (Mignucci-Giannoni et al. 1999a); this species has not been recorded for the Virgin Islands (Debrot et al. 2013). There are no records of this species for the proposed survey areas in the OBIS database (OBIS 2021).

#### 3.3.2.17 Short-finned Pilot Whale (*Globicephala macrorhynchus*)

The short-finned pilot whale is found in tropical and warm temperate waters (Olson 2018); it is seen as far south as ~40ºS and as far north as ~50ºN (Jefferson et al. 2015). Pilot whales are generally nomadic and occur on the shelf break, over the slope, and in areas with prominent topographic features (Olson 2018). In the western North Atlantic, short-finned pilot whales occur from Virginia to northern South America, including the Caribbean and Gulf of Mexico (Würsig et al. 2000). Téllez et al. (2014) reported that short-finned pilot whales in the Caribbean show substantial genetic diversity.

Numerous sightings have been made in Puerto Rico and the Virgin Islands, most of which occurred over the shelf (Mignucci-Giannoni 1998; DoN 2002). Short-finned pilot whales were observed in Mona Passage, off western Puerto Rico, during spring 2013, winter 2014, and winter 2015 (MacKay and Bacon 2019), and in the proposed survey area north of Puerto Rico during winter 1995 (Roden and Mullin 2000). Rodriguez-Ferrer et al. (2018) reported another five sightings along the shelf edge and in deep offshore waters off Puerto Rico during for 1996, 2009, and 2016, and 2018, and Swartz et al. (2002) reported several other sightings off Puerto Rico during February–March 2001. Opportunistic sightings of short-finned pilot whales have also been reported for the Dominican Republic (Whaley et al. 2006). There are three records of short-finned pilot whales and nine records of *Globicephala* sp. within or near the proposed survey areas in the OBIS database (OBIS 2021).

#### 3.3.2.18 Killer Whale (*Orcinus orca*)

The killer whale is cosmopolitan and globally fairly abundant; it has been observed in all oceans of the world (Ford 2018). It is very common in temperate waters and also frequents tropical waters, at least seasonally (Heyning and Dahlheim 1988). Killer whales tend to be more common in nearshore areas and at higher latitudes (Jefferson et al. 2015). The greatest abundance is thought to occur within 800 km of major continents (Mitchell 1975). In the Northwest Atlantic, killer whales occur from the polar pack ice to Florida and the Gulf of Mexico (Würsig et al. 2000). Numerous sightings have been reported for Puerto Rico and the Virgin Islands, as well as one stranding and a capture for the Dominican Republic (Mignucci-Giannoni 1998; Bolaños-Jiménez et al. 2014); sightings were made throughout the year. DoN (2002) reported one sighting during fall within the proposed survey area north of Puerto Rico. There are nearly 30 records within or near the proposed survey areas in the OBIS database (OBIS 2021).

#### 3.3.2.19 False Killer Whale (*Pseudorca crassidens*)

The false killer whale is found worldwide in tropical and temperate waters, generally between 50ºN and 50ºS (Odell and McClune 1999). It is widely distributed, but rare to uncommon throughout its range (Baird 2018b). It generally inhabits deep, offshore waters, but sometimes is found over the continental shelf and occasionally moves into very shallow water (Jefferson et al. 2015; Baird 2018b). It is gregarious and forms strong social bonds, as is evident from its propensity to strand en masse (Baird 2018b). In the Northwest Atlantic, it occurs from Maryland to the Gulf of Mexico and the Caribbean (Würsig et al. 2000). Merten and Rodriguez-Ferrer (2014) reported the first stranding and sighting of false killer whales off Puerto Rico in January and March 2013, respectively; the sighting was of two adults and a calf in offshore waters ~40 km south of Puerto Rico, and the stranding consisted of one male. Swartz et al. (2002) reported one sighting of nine individuals during March 2002 in offshore waters southwest of Puerto Rico. Rodriguez-Ferrer et al. (2018) reported one other sighting in Mona Passage in February 2018. Two sightings have been reported for the Virgin Islands (Mignucci-Giannoni 1998; DoN 2002) and one stranding (Mignucci-Giannoni 1996; Mignucci-Giannoni et al. 1999a). For the proposed survey areas, there is one record off the southern coast of Puerto Rico in the OBIS database (OBIS 2021).

#### 3.3.2.20 Pygmy Killer Whale (*Feresa attenuata*)

The pygmy killer whale has a worldwide distribution in tropical waters (Baird 2018c), generally not ranging south of 35°S (Jefferson et al. 2015). It is found in nearshore areas where the water is deep and in offshore waters (Jefferson et al. 2015). It is known to inhabit the warm waters of the Indian, Pacific, and Atlantic oceans (Jefferson et al. 2015). In the Northwest Atlantic, it occurs from the Carolinas to Texas and the West Indies, and the Gulf of Mexico (Würsig et al. 2000). A group of five pygmy killer whales stranding at Beef Island (Tortola) in the British Virgin Islands on 16 September 1995; this was the second record of this species in the Caribbean (Mignucci-Giannoni et al. 1999c); the first record was for St. Vincent (Caldwell and Caldwell 1971). Numerous other strandings records have been reported for the British Virgin Islands (Mignucci-Giannoni 1996). Another pygmy killer whale live stranded on the northwestern coast of Puerto Rico on 25 February 1997 (Rodríguez-López and Mignucci-Giannoni 1999). For the proposed survey areas, there is one record off the northeastern coast of Puerto Rico in the OBIS database (OBIS 2021).

#### 3.3.2.21 Melon-headed Whale (*Peponocephala electra*)

The melon-headed whale is an oceanic species found worldwide in tropical and subtropical waters from ~40°N to 35°S (Jefferson et al. 2015). It is commonly seen in mixed groups with other cetaceans (Jefferson and Barros 1997). It occurs most often in deep offshore waters and occasionally in nearshore areas where deep oceanic waters occur near the coast (Perryman and Danil 2018). In the western Atlantic, its range extends from the Gulf of Mexico to southern Brazil (Rice 1998). There are few records for the Caribbean, but one stranding of a juvenile male was reported for Puerto Rico on 17 August 1993

(Mignucci-Giannoni 1996, 1998; Mignucci-Giannoni et al. 1999a). There are no records for the proposed survey areas in the OBIS database (OBIS 2021).

## 3.4 Sea Turtles

Of the world's seven species of sea turtles, five species could occur in the proposed study area – loggerhead, green, hawksbill, olive ridley, and leatherback turtles. Under the ESA, the leatherback and hawksbill sea turtles are listed as ***endangered***; the olive ridley population in the Atlantic Ocean, the Northwest Atlantic DPS of loggerhead turtle, and the North Atlantic and South Atlantic DPSs of the green sea turtle are listed as ***threatened*** (Table 6). The U.S. and Dominican Republic are signatories of the Inter-American Convention (IAC) for the Protection and Conservation of Sea Turtles.

The IAC complies with CITES and prohibits the deliberate take or harvesting of sea turtles or their eggs (IAC 2015). Leatherback, loggerhead, green, and hawksbill sea turtles nest in the Wider Caribbean Region (WCR) (Piniak and Eckert 2011; Eckert and Eckert 2019), although loggerhead turtles do not nest on the beaches adjacent to the study area (Eckert and Eckert 2019). Olive ridley turtles nest in some locations in the WCR and have just recently been recorded to nest on Puerto Rico (González-García et al. 2021). The migratory paths of leatherback, green, and hawksbill sea turtles are also known to traverse the proposed survey areas (e.g., Blumenthal et al. 2009). Foraging concentration areas identified within the proposed survey areas include Puerto Rico (Culebra and Mona islands), Dominican Republic (Jaragua National Park and Cabo Rojo), and the U.S. and British Virgin Islands.

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 in the Northwest Atlantic and Caribbean Sea are discussed in § 3.4.2.1 and 3.4.2.2 of the PEIS, respectively. The rest of this section deals specifically with the distribution of sea turtles within the proposed survey areas off Puerto Rico.

### 3.4.1 Leatherback Turtle (*Dermochelys coriacea*)

The leatherback is the most widely distributed sea turtle, occurring from 71°N to 47°S (Eckert et al. 2012). During the non-breeding season, the leatherback turtle undertakes long-distance migrations between its tropical and subtropical nesting grounds, located between 38°N and 34°S, and high-latitude foraging grounds in continental shelf and pelagic waters (Eckert et al. 2012). The species is known to traverse entire ocean basins (Valverde and Holzwart 2017) and has the longest migrations (up to 5000 km) of any reptile. Juveniles are oceanic and likely spend their early years in tropical waters until they reach a length of ~100 cm, when they can be found in more temperate waters (Eckert et al. 2012).

In the western Atlantic Ocean, leatherbacks are known to range from Greenland to Argentina. The number of nesting females in the Northwest Atlantic is 20,659 (NMFS and USFWS 2020). Leatherback sea turtle nesting in the WCR occurs predominantly at colonies in Panama, Trinidad, Suriname, and French Guiana, with lesser colonies in Costa Rica, Guyana, and the U.S. Virgin Islands (Piniak and Eckert 2011).

The nesting season for the leatherback sea turtle in the WCR is February through August (Valverde and Holzwart 2017). The leatherback nests at the beaches adjacent to the proposed survey areas in the Dominican Republic, Puerto Rico, and the U.S. and British Virgin Islands (Hasting 2003; Revuelta 2014; Eckert and Eckert 2019). The leatherback is known to forage in the Puerto Rico EEZ (Piniak and Eckert 2011; Eckert and Eckert 2019).

TABLE 6. The habitat, occurrence, and conservation status of sea turtles that could occur in or near the proposed project area off Puerto Rico in the Northwest Atlantic Ocean.

| Species | Habitat | Occurrence in Study Area | US ESA[1] | SPAW[2] | Dominican Republic Red List[3] | IUCN[4] | CITES[5] |
|---|---|---|---|---|---|---|---|
| Leatherback sea turtle | Beaches (nesting females); oceanic (juveniles and foraging adults) | Uncommon | E | II | EP | EN[6] | I |
| Loggerhead sea turtle<br>Northwest Atlantic DPS | Beaches (nesting females); coastal/oceanic (juveniles); coastal (foraging adults); oceanic (migration) | Common | T | II | VU | LC[7] | I |
| Green sea turtle<br>North Atlantic DPS | Beaches (nesting females); oceanic (juveniles and migrating adults); coastal (foraging adults) | Common | T | II | EP | EN | I |
| Green sea turtle<br>South Atlantic DPS | Beaches (nesting females); oceanic (juveniles and migrating adults); coastal (foraging adults) | Uncommon | T | II | EP | EN | I |
| Hawksbill sea turtle | Beaches (nesting females); coastal/oceanic (juveniles); coastal (foraging adults) | Common | E | II | PC | CR | I |
| Olive ridley sea turtle | Beaches (nesting females); coastal/oceanic (juveniles and adults) | Uncommon | T[8] | II | NL | VU | I |

NL = Not Listed. [1] U.S. Endangered Species Act: E = Endangered, T = Threatened. [2] Specially Protected Areas and Wildlife Protocol of the Cartagena Convention: Annex II, strictly protected fauna. Accessed at https://www.unep.org/cep/what-we-do/specially-protected-areas-and-wildlife-spaw. [3] Lista de especies en peligro de extinción, amenzadaso protegidas de la República Dominicana, List Roja (Ministro de Medio Ambiente y Recursos Naturales 2011): EP = En Peligro (very high risk of extinction in the wild in the near future); PC = Peligro Critico (extremely high risk of extinction); VU = Vulnerable (risk of extinction in the medium term). [4] International Union for the Conservation of Nature Red List of Threatened Species, version 2021-1: CR = critically endangered, EN = endangered, VU = vulnerable, LC = least concern. [5] Convention on International Trade in Endangered Species: Appendix I, species that are the most endangered and are considered threatened with extinction. [6] Globally, the leatherback turtle is listed as vulnerable, but the Northwest Atlantic population is considered endangered. [7] Globally, the loggerhead is listed as vulnerable, but the North West Atlantic population is considered least concern. [8] All populations except Mexico's Pacific coast breeding population.

Nesting beaches with 500–1000 nesting crawls (or tracks) per year are found in the Dominican Republic and Puerto Rico (Eckert and Eckert 2019). In the Dominican Republic, the main nesting beach is in Jaragua National Park, with ~100 nests per year (Revuelta 2014; Revuelta et al. 2012, 2015); the nesting season extends from March–August and peaks in May (Revuelta 2014; Revuelta et al. 2012). Other nesting beaches in the Dominican Republic have up to 50 nests per year (Revuelta 2014). A small percentage of nesting females switch nesting grounds between nesting attempts within the same nesting season. Some females have been known to switch nesting beaches within St. Croix (U.S. Virgin Islands), and others have switched between beaches in St. Croix and Culebra (Puerto Rico) (Eckert et al. 1989) and Culebra and the British Virgin Islands (Hasting 2003). Keinatch and Musick (1993 *in* DoN 2002) reported nesting by a leatherback sea turtle at three different sites during one season, including Sandy Point on St. Croix, and Vieques and Culebra islands, Puerto Rico.

Leatherbacks nesting in the Dominican Republic are not genetically distinct from other nesting populations in the WCR, with the exception of Trinidad and Suriname (Carreras et al. 2013). Nesting attempts in the British Virgin Islands has increased from 3 in 1991 to 63 in 2001; most nesting occurs along the northern coast of Tortola and at Beef Island (Hasting 2003). NMFS (1979) designated critical habitat for leatherback turtles off the southwestern coast of St. Croix, U.S. Virgin Islands (Fig. 1), adjacent to a nesting beach that was designated as critical habitat by USFWS; the marine critical habitat includes the waters from the hundred fathom survey to the high tide mark (NMFS 1979).

The OBIS database (2021) shows numerous records in nearshore and offshore waters within and near the proposed study area, including within the EEZs of Puerto Rico, U.S. Virgin Islands, and British Virgin Islands; sightings were made throughout the year. DoN (2002) reported nearshore sightings and strandings for Puerto Rico during fall.

### 3.4.2 Green Turtle (*Chelonia mydas*)

The green sea turtle is the largest of the hard-shelled turtles, exceeded in size only by the leatherback (Valverde and Holzwart 2017). Green sea turtles are widely distributed in tropical and subtropical waters, spending most of their lives in coastal foraging areas (Seminoff et al. 2015). Nesting occurs in more than 80 countries worldwide (Valverde and Holzwart 2017). Oceanic waters are used by juveniles and migrating adults, and sometimes for foraging by adults. Immature green turtles aggregate in certain neritic areas to forage. Seasonal migrations between nesting and foraging areas cover distances as much as thousands of kilometres (Lageux 2001). Nesting occurs at intervals of two to four years, and females average three clutches per nesting season (Lageux 2001). In 2016, the species was divided into 11 DPSs globally for ESA-listing purposes (NMFS 2016c). Most green sea turtles near the proposed survey areas belong to the North Atlantic DPS, although some individuals could be from the South Atlantic DPS. For example, Foley et al. (2007) found that 4% of green turtles in the Gulf of Mexico were not from U.S., Mexican, or Costa Rican rookies; thus, it is likely that these turtles originated from the South Atlantic DPS. Bjorndal et al. (2017) found that mean growth rates of green turtles in the West Atlantic decreased by 26% between 1999 and 2015, likely partially due to increased water temperatures.

Green sea turtles nest throughout the WCR. The largest nesting colony is on Tortuguero Beach in Costa Rica, with >100,000 nests annually (Piniak and Eckert 2011). Other major nesting beaches in the Atlantic with >500 nesting attempts annually are broadly distributed elsewhere in Costa Rica and in French Guiana, Mexico, Suriname, and the U.S. (mainly Florida), as well as islands off Venezuela and Cuba. This species nests and forages in the Dominican Republic, Puerto Rico, and the U.S. and British Virgin Islands (Piniak and Eckert 2011; Eckert and Eckert 2019). Countries and territories with beaches that have >500 nesting crawls per year include the Dominican Republic and U.S. Virgin Islands (Eckert and

Eckert 2019). The number of clutches recorded per year consist of 55 in the Dominican Republic (all on the north coast, with the greatest number at Saona Island), 142 clutches in Puerto Rico (Culebra Archipelago), 199 in the British Virgin Islands, and 401 in the U.S. Virgin Islands (SWOT 2011). In Puerto Rico, green sea turtles mainly nest along the east coast, as well as on Vieques Island off the east coast and Mona Island off the west coast; Vieques Island has 100–500 crawls per year (Eckert and Eckert 2019). Green sea turtle nesting season in the WCR occurs from May through September (Valverde and Holzwart 2017). In the British Virgin Islands, nesting peaks in August (McGowan et al. 2008).

The largest feeding aggregation in the WCR is in Nicaragua, and smaller aggregations are found in a variety of countries and territories, including Puerto Rico (Lageux 2001). In Puerto Rico, neritic areas of Culebra (Puerto Manglar and Tortuga Bay) are used by green turtles ranging in age from small immatures to large immatures and adults (Patrício et al. 2011). They remain in these bays for 10–17 years (Patrício et al. 2014). In Culebra, green turtles prefer lagoon habitat, followed by seagrass habitat, and are much less likely to use macroalgae habitat (Griffin et al. 2019). The waters surrounding Culebra have been designated as critical habitat for the green turtle (NMFS 1998) (Fig. 1). Federal management and conservation measures are mandatory within 5.6 km of coast of the archipelago (NMFS 1998; Griffin et al. 2019). Green turtles foraging in the Culebra Archipelago come from nesting beaches largely in Costa Rica, Mexico, east-central Florida, and Suriname, with smaller numbers from south Florida, Cuba, and Guinea-Bissau (Patrício et al. 2017). Tag recoveries suggests that some may also come from northern Brazil (Lima et al. 2008). Green turtles that were tagged on Aves Island, Venezuela, and Costa Rica were recorded in the Dominican Republic and Puerto Rico (Carr et al. 1978; Solé 1994; Tröeng et al. 2005), and a turtle tagged in Bermuda was tracked to the Dominican Republic (Meylan et al. 2011). One female green turtle that was tagged in Turks and Caicos on 25 June 2009 migrated through the Caribbean before returning to foraging grounds in Turks and Caicos on 27 January 2010; she traveled through the proposed survey area north of the Dominican Republic, Puerto Rico, and the Virgin Islands (Richardson et al. 2010). Another green turtle that was tagged in Cuba was found stranded 22 years later on Vieques, Puerto Rico (Moncada et al. 2020). The relatively high abundance of green turtles in the British Virgin Islands suggests that those waters are an important foraging area for this species (McGowan et al. 2008).

The OBIS database (2021) shows numerous records in nearshore waters of Vieques Island, Puerto Rico, as well as a few sightings in nearshore and offshore waters of the EEZs of Puerto Rico and British Virgin Islands; sightings were made throughout the year. DoN (2002) reported numerous sightings in nearshore waters within the EEZs of Puerto Rico and the Virgin Islands, including numerous sightings during fall around Vieques Island.

### 3.4.3 Hawksbill Sea Turtle (*Eretmochelys imbricata*)

Hawksbill sea turtles are the most tropical of all sea turtles, ranging throughout tropical and subtropical regions of Northwest Atlantic Ocean and WCR (Valverde and Holzwart 2017). Juveniles, sub-adults, and adults forage in coastal waters primarily in coral reefs, but also around rocky outcrops, high energy shoals, mangrove-fringed bays, and estuaries (summarized in Amorocho 2001). Long-distance international movements indicate that this species is migratory (e.g., Meylan 1999a; Van Dam et al. 2008). Bjorndal et al. (2017) noted that mean growth rates of hawksbill turtles in the West Atlantic decreased by 18% between 1997 and 2013, likely as a result from increased water temperatures. Many populations in the Caribbean are thought to be declining (Meylan 1999b).

This species shows high fidelity to nesting beaches and returns to nest at 2.5-year intervals (Amorocho 2001). Nesting takes place primarily from July–October but occurs year-round at some locations (Amorocho 2001). Females lay an average of five clutches per year at intervals of 14–16 days

(Amorocho 2001). Hawksbills nest at low densities throughout the WCR (Piniak and Eckert 2011). Hawksbills aggregate for nesting and foraging in the Dominican Republic, Puerto Rico, and the U.S. and British Virgin Islands (Piniak and Eckert 2011; Eckert and Eckert 2019). Nesting populations are genetically distinguishable, but foraging aggregations are composed of individuals from multiple nesting grounds (Amorocho 2001).

Approximately 5000 hawksbill turtles nest in the WCR (e.g., NMFS and USFWS 2013; Meylan 1999b). According to Eckert and Eckert (2019), nesting beaches with more than 1000 nesting crawls per year include Puerto Rico (Mona Island) and the Dominican Republic (Catalina Island and Soana Island). In the Dominican Republic, Saona Island off the southeast coast of the country has the largest concentration of hawksbill nesting, with 100–500 nests annually during 2006–2010 (Revuelta 2014). Other nesting beaches in the Dominican Republic have up to 25 nests per year, including sites in Jaragua National Park (Revuelta 2014). During inter-nesting intervals females remain in shallow waters adjacent to their nesting beaches (Revuelta et al. 2015). Most nesting female hawksbills tagged with satellite transmitters on Saona Island have been tracked to waters off Nicaragua, Honduras, and the Bahamas, but some individuals remained in Dominican Republic waters (Hawkes et al. 2012; Tomás et al. 2011; Carreras et al. 2013). Female philopatry to natal nesting areas in this species has resulted in the two nesting populations at Saona Island becoming genetically distinct and has also resulted in their genetic divergence from almost all other nesting populations in the WCR except those in Puerto Rico, U.S. Virgin Islands, and Belize (Carreras et al. 2013). One adult female tagged in Yucatán, Mexico, in 1967 was recaptured in the Dominican Republic in April 1971 (Meylan 1999a). Immature turtles that were tagged at St. Thomas, U.S. Virgin Islands, were recaptured in the Dominican Republic, British Virgin Islands, and Puerto Rico (Meylan 1999a).

Foraging grounds at Jaragua National Park and Cabo Rojo, both in the Dominican Republic, are important aggregations and are composed primarily of juveniles and sub-adults (Aucoin and Leon 2008; León and Diez 1999). Concentrations of foraging hawksbills in the British Virgin Islands, especially at Anegada, suggest that the area is relatively important for this species in the WCR (McGowan et al. 2008). Meylan (1999a) noted that juveniles at feeding grounds show long-term residency at these developmental habitats. Individuals breeding at Puerto Rico and the U.S. Virgin Islands make up a portion of the foraging aggregation in the Cayman Islands (Blumenthal et al. 2009).

The reefs and cliff walls surrounding Mona Island, Puerto Rico, support a large aggregation of foraging hawksbills of all ages (León and Diez 1999; Van Dam and Diez 1998; Velez-Zuazo et al. 2008). Breeding females and males tagged at Mona Island travelled from <2 km to 2051 km in <1–22 days to foraging grounds in seven countries and territories, including the U.S. and British Virgin Islands, and the Dominican Republic (Van Dam et al. 2008). The feeding aggregation at Mona Island shows genetic markers primarily of individuals nesting in the U.S. Virgin Islands and the Yucatan Peninsula (Bowen et al. 1996). NMFS has designated the waters surrounding Mona and Monito islands in Puerto Rico, from the mean high-water line to 5.6 seaward, as critical habitat (NMFS 1998). The population at Mona Island is increasing (Meylan 1999b; NMFS and USFWS 2013), as are populations in the rest of Puerto Rico and U.S. Virgin Islands (NMFS and USFWS 2013). At Culebra, juvenile hawksbill turtle have been found to forage selectively and not necessarily on abundant prey types (Rincon-Diaz et al. 2011a); the structural complexity of benthic habitat rather than food availability explained turtle abundance in the region (Rincon-Diaz et al. 2011b).

The OBIS database (2021) shows numerous records in nearshore waters of Vieques Island and in the British Virgin Islands, as well as numerous other sightings in nearshore and offshore waters of the EEZs of the Dominican Republic, Puerto Rico, U.S. Virgin Islands, and British Virgin Islands. Most records were for October–February, but sightings were made year-round (OBIS 2021). DoN (2002) also reported numerous sightings in nearshore waters within the EEZs of Puerto Rico and the Virgin Islands, including numerous sightings during fall around Vieques Island.

### 3.4.4 Olive Ridley Sea Turtle (*Lepidochelys olivacea*)

Olive ridley turtles are pantropical, occurring in waters with temperatures of at least 20ºC or 68ºF; they have a large range in the Pacific, Indian, and South Atlantic oceans. They travel between breeding and feeding grounds in continental coastal waters and are rare around oceanic islands. The worldwide population of olive ridley turtles is estimated at 2 million nesting females (Spotila 2004). The olive ridley sea turtle may be the most abundant species of sea turtle in the world and is found in all tropical and subtropical ocean basins (Marcovaldi 2001). Distinct populations are found in coastal habitats, but a few have been captured far offshore (Marcovaldi 2001).

This species occurs rarely in most of the WCR, but nests in Suriname, French Guiana, Trinidad, and Brazil, totaling 1400–1600 nests (Eckert and Eckert 2019; González-García et al. 2021; Marcovaldi 2001). Although Eckert and Eckert (2019) noted that this species is absent from the Dominican Republic and Virgin Islands, González-García et al. (2021) reported recent sightings in the waters off the Dominican Republic, U.S. Virgin Islands, and Cuba. Piniak and Eckert (2011) and Eckert and Eckert (2019) did report infrequent foraging by this turtle in Puerto Rico, and it has recently been recorded nesting in Puerto Rico for the first time (González-García et al. 2021). A total of 64 nesting sites have been recorded in the WCR (Piniak and Eckert 2011; González-García et al. 2021). Migrations and other movements have been documented in coastal areas of Venezuela, the Guianas, and Brazil, but little else is known about movements or behavior at sea in the western Atlantic (Marcovaldi 2001). The olive ridley lays two to three clutches per year, often in consecutive years (Marcovaldi 2001). Following nesting, individuals migrate to foraging areas independently (Marcovaldi 2001). There are no records in the OBIS database (2021) for the EEZs of the Dominican Republic, Puerto Rico, U.S. Virgin Islands, or British Virgin Islands. DoN (2002) reported one stranding along the northwest coast of Puerto Rico.

### 3.4.5 Loggerhead Sea Turtle (*Caretta caretta*)

The loggerhead sea turtle is widely distributed, occurring in tropical, subtropical, and temperate waters of the Atlantic, Pacific, and Indian oceans (Valverde and Holzwart 2017). Adults generally forage in coastal and shelf waters but can pass through oceanic waters during migrations. In 2011, the species was divided into nine DPSs globally for ESA-listing purposes (NMFS 2011), with the Northwest Atlantic Ocean DPS occurring in the proposed survey areas. This species' distribution extends into more temperate waters than other sea turtles. Bjorndal et al. (2013) found that mean growth rates of loggerhead turtles in the West Atlantic decreased between 1997–2007, but then leveled off or even increased.

The nesting season for the Northwest Atlantic loggerhead DPS is from April through September (Valverde and Holzwart 2017). In the Caribbean region, it nests primarily in Florida, Mexico, and Brazil, with smaller numbers nesting in Haiti, Cuba, Bahamas, Turks and Caicos, Cayman Islands, Monserrat, and Central America (Eckert and Eckert 2019). Piniak and Eckert (2011) and Eckert and Eckert (2019) reported that it is occurs infrequently off the Dominican Republic, Costa Rica, and the U.S. and British Virgin Islands, but does not nest there. Juvenile loggerhead turtles may be transported along the northern coast of the Greater Antilles by the currents (Gavilán 2001). The Northwest Atlantic Ocean DPS was estimated to consist of a minimum of 30,096 adult females, with most of these occurring off peninsular Florida and perhaps a few thousand in the rest of the WCR (Richards et al. 2011). The OBIS database (2021) shows numerous records in nearshore waters of Vieques Island and eastern Puerto Rico, as well as numerous other sightings in offshore waters of the Dominican Republic, Puerto Rico, and U.S. Virgin Islands; most records are for July–October.

## 3.5 Seabirds

The deep warm tropical waters off the north side of Puerto Rico have a relatively low diversity of seabirds. Abundant North Atlantic seabirds such as great shearwater (*Ardenna gravis*) and sooty shearwater (*Ardenna grisea*) bypass this area on their spring migration to more northern feeding ground. However, most of the tropical seabirds found throughout the Caribbean Sea also occur in Puerto Rico. However, the only ESA-listed seabird species that could occur in the proposed survey areas is the ***threatened*** roseate tern; the black-capped petrel could also occur in the region and is proposed for listing as ***threatened*** (Table 7).

### 3.5.1 Roseate Tern (*Sterna dougallii*)

The roseate tern has a worldwide distribution mainly in tropical and subtropical oceans. It is a strictly marine species feeding on small fish. Roseate terns typically feed in shelf waters, but they are also known to forage up to 30 km from nesting sites. Nesting colonies occur throughout the Caribbean, including Puerto Rico and the Virgin Islands (USFWS 2010). In Puerto Rico, they nest on the Northwest Cays, Southwestern Cays, Culebra archipelago, and Vieques Island (USFWS 2010). In 2009, roseate tern colonies in the Northwest Cays and Southwestern Cays were estimated at ~300 pairs and 943 pairs, respectively (USFWS 2010). Roseate terns arrive at La Parguera, Puerto Rico, in late-April to early-May; egg-laying begins in mid to late May. Adults and fledged young leave Puerto Rico in late August and September for wintering areas at unknown coastal regions of South America (USFWS 2010).

Besides nesting terns, migrants from northern populations use Puerto Rico as a staging area during migration. Geolocator data from six roseate terns tagged at Bird Island, Massachusetts, showed that southbound migration flight paths were transoceanic until reaching Puerto Rico and the Dominican Republic (USFWS 2020). Five of the six birds remained in the vicinity for 7–13 days before continuing southward to Suriname/Guyana and northern Brazil. In addition, birds banded in the northeast have been resighted in Puerto Rico in September (USFWS 2020). As roseate terns can forage up to 30 km from nesting sites, they could occur within the survey areas, in particular the USGS survey area in the Caribbean Sea. However, roseate terns typically feed in shelf waters, and none of the surveys would take place in water depths <100 m, with most of the high-energy seismic surveys occurring >30 km from the coast. Most roseate terns would have passed through the area and migrated south by late-August to mid-September.

### 3.5.2 Black-capped Petrel (*Pterodroma hasitata*)

The black-capped petrel nests in the countries of Haiti and the Dominican Republic from October–May (Carboneras et al. 2020). Nesting habitat occurs on very steep vegetated slopes, usually well inland. The nest is at the end of a burrow dug into the soft earth; the birds enter and leave the nest only under the cover of darkness. There are four extant breeding populations on Hispaniola, but the populations are small and suitable nesting habitat is limited and decreasing. The population is estimated at no more than 1000 breeding pairs, but perhaps as few as 500, and a total population of 2,000–4,000 birds (BirdLife International 2021). Deforestation due to human dependence on wood-based cooking fuel and clearing for agricultural purposes are the biggest risks to the black-capped petrel. The black-capped petrel is highly pelagic, occurring in offshore waters beyond the shelf edge, including off Puerto Rico. It is likely a year-round resident in the survey areas. It travels long distances from nesting sites to forage for small fish and cephalopods (Carboneras et al 2020). During the non-breeding season its core range extends northward in the Gulf Stream as far north as North Carolina.

TABLE 7. The habitat, occurrence, regional population sizes, and conservation status of protected marine-associated birds that could occur in or near the proposed project area in the Northwest Atlantic Ocean.

| **Species** | **Occurrence in Study Area during Fall/Winter[1]** | **U.S. ESA[2]** | **SPAW[3]** | **Dominican Republic Red List[4]** | **IUCN[5]** | **CITES[6]** |
|---|---|---|---|---|---|---|
| Black-capped Petrel | Uncommon, pelagic | T (Proposed) | NL | PC | EN | NL |
| Roseate Tern | Scarce; mainly coastal; migrating individuals head south during fall | T | II | VU | LC | NL |

NL = Not Listed. [1] Occurrence based on available data and professional opinion. [2] U.S. Endangered Species Act; T = Threatened. [3] Specially Protected Areas and Wildlife Protocol of the Cartagena Convention: Annex II, strictly protected fauna; NL = not listed. Accessed December 2021 at https://www.unep.org/cep/what-we-do/specially-protected-areas-and-wildlife-spaw. [4] Lista de especies en peligro de extinción, amenzadaso protegidas de la República Dominicana, List Roja (Ministro de Medio Ambiente y Recursos Naturales 2011): PC = Peligro Critico (extremely high risk of extinction); VU = Vulnerable (risk of extinction in the medium term). [5] International Union for the Conservation of Nature Red List of Threatened Species, version 2021-1: EN = endangered, LC = least concern. [6] Convention on International Trade in Endangered Species.

## 3.6 Fish and Marine Invertebrates, Essential Fish Habitat, and Habitat Areas of Particular Concern

There are five fish species listed under the ESA that could occur in the survey areas, including the ***endangered*** giant manta ray and smalltooth sawfish, and the ***threatened*** Nassau grouper, oceanic whitetip shark, and Central & Southwest Atlantic DPS of scalloped hammerhead shark (Table 8). Both the U.S. and the non-U.S. populations of smalltooth shark are listed under the ESA and could occur within the proposed survey areas. The largetooth sawfish (*Pristis pristis*) is listed as endangered under the ESA, but it occurs in shallow water <100 m where no survey effort would occur; it is not discussed further.

One marine invertebrate species in the WCR, the queen conch, is proposed for listing under the ESA as ***threatened*** and could also occur in the survey area; however, adults of this species generally occur in water <40 m deep, although larvae could occur in deeper water, but generally <100 m deep. No other ESA-listed marine invertebrate species could occur in the proposed project area. Several ESA-listed coral species occur in the region at large but are unlikely to occur in the survey areas due to their shallow depth ranges (maximum depth of <50 m). These species include the *threatened* elkhorn coral (*Acropora palmata*), staghorn coral (*A. cervicornis*), boulder star coral (*Orbicella franksi*), mountainous star coral (*O. faveolata*), lobed star coral (*O. annularis*), rough cactus coral (*Mycetophyllia ferox*), and pillar coral (*Dendrogyra cylindrus*). Critical habitat for elkhorn and staghorn corals has been designated in water <30 m deep around Puerto Rico and U.S. Virgin Islands (NMFS 2008; Fig. 1). Critical habitat for the other threatened coral species has been proposed by NMFS for shallow waters (<100 m) around Puerto Rico and U.S. Virgin Islands, but has not yet been designated (NMFS 2020).

Additionally, queen conch, Caribbean spiny lobster (*Panulirus argus*), and all soft and hard coral species (including orders Scleractinia, Alcyonacea, Antipatharia, and Milleporina/Anthoathecata) are listed in Annex III of the SPAW Protocol of the Cartagena Convention, meaning exploitation of these species is regulated.

TABLE 8. The habitat, occurrence, and conservation status of fish and marine invertebrate species of conservation concern that could occur in or near the proposed project area off Puerto Rico, in the Northwest Atlantic Ocean.

| **Species** | **Habitat** | **Occurrence in Study Area**[1] | **US ESA**[2] | **SPAW**[3] | **Dominican Republic Red List**[4] | **IUCN**[5] | **CITES**[6] |
|---|---|---|---|---|---|---|---|
| **Fish** | | | | | | | |
| Nassau Grouper | Reef structure >130 m | Common | T | III | PC | CR | NL |
| Giant Manta Ray | Coastal-pelagic; migratory; deep-diving | Uncommon | E | III | NL | VU | II |
| Smalltooth Sawfish | Freshwater, estuarine, coastal >122 m | Rare | E | II | NL | CR | I |
| Oceanic Whitetip Shark | Pelagic; open ocean; migratory | Rare | T | III | NL | CR | II |
| Scalloped Hammerhead Shark | Coastal-pelagic, semi-pelagic; migratory | Common | T | III | EP | CR | II |
| **Invertebrates** | | | | | | | |
| Queen Conch | Coastal benthic <100 m | Potentially Larvae only | T (Prop.) | III | EP | NL | II |

NL = Not Listed. [1] Occurrence based on available data and professional opinion. [2] U.S. Endangered Species Act; E = Endangered, T = Threatened. [3] Specially Protected Areas and Wildlife Protocol of the Cartagena Convention: Annex II, strictly protected fauna; NL = not listed. Accessed December 2021 at https://www.unep.org/cep/what-we-do/specially-protected-areas-and-wildlife-spaw. [4] Lista de especies en peligro de extinción, amenzadaso protegidas de la República Dominicana, List Roja (Ministro de Medio Ambiente y Recursos Naturales 2011): EP = En Peligro (very high risk of extinction in the wild in the near future); PC = Peligro Critico (extremely high risk of extinction); VU = Vulnerable (risk of extinction in the medium term). [5] International Union for the Conservation of Nature Red List of Threatened Species, version 2021-1: CR = critically endangered, VU = vulnerable, NL = not listed. [6] Convention on International Trade in Endangered Species of Wild Fauna and Flora: Appendix I = Threatened with extinction; Appendix II = not necessarily now threatened with extinction but may become so unless trade is closely controlled.

## 3.6.1 Fish Species of Conservation Concern

### 3.6.1.1 Nassau Grouper (*Epinephelus striatus*)

Nassau grouper inhabit high-relief reef structures, both natural and artificial, from Bermuda to Florida, westward to the Yucatán Peninsula and throughout the Caribbean Sea, with larger fish generally moving to deeper water up to 130 m (NMFS 2018b). Adults exhibit solitary behavior but temporarily form synchronized spawning aggregations, in which sexually mature fish aggregate at predictable locations from November–February to release their gametes. These aggregations have declined and continue to decline in both number of fish and number of aggregations throughout the species' range (Sadovy de Mitcheson 2012; NMFS 2018b). Eggs and larvae are dispersed via wind and currents throughout their range during the 5- to 6-week planktonic period (Shenker et al. 1993).

### 3.6.1.2 Giant Manta Ray (*Manta birostris*)

Giant manta rays are long-lived, migratory, planktivorous fish, with highly fragmented populations sparsely distributed in the tropical, subtropical, and temperate waters of the world (NOAA 2022a). Giant manta rays are the largest living ray in the world and tend to be solitary except for feeding and breeding periods in which individuals aggregate (NOAA 2022a). Populations have declined and continue to decline worldwide, and low reproductive potential greatly limits the species' ability to recover from decreases in abundance (NMFS 2019a). Giant manta rays may be found in shallow water under 10 m but tagged individuals have been shown to dive up to 200–450 m and may make dives >1000 m, possibly depending on prey distribution (NOAA 2022a).

#### 3.6.1.3 Smalltooth Sawfish (*Pristis pectinata*)

The smalltooth sawfish is a long-lived ray species that was named for its large, flat, toothed rostrum. Its historical range has been significantly reduced through time due in large part to habitat loss and fishing mortality, but it can still be found in Florida, the Bahamas, Cuba, other Caribbean waters, and Sierra Leone (NOAA 2022b). The smalltooth sawfish spends most of its time in warm shallow waters <10 m deep (Carlson et al. 2014), including coastal, estuarine, and freshwater habitats, but larger adults are commonly found in deeper water offshore (NMFS 2009). Smalltooth sawfish reach sexually maturity at ~7 years of age and have a somewhat low reproductive output, making recovery from population decreases a slow process (NFMS 2009).

#### 3.6.1.4 Oceanic White Tip Shark (*Carcharhinus longimanus*)

The oceanic whitetip shark is a highly migratory offshore pelagic species occurring worldwide, typically between 20ºN and 20ºS in tropical and subtropical seas (NOAA 2022c). It tends to inhabit surficial waters up to at least 152 m deep (NMFS 2018c) and is an opportunistic feeder, preying on a variety of bony fishes and large sport fish, cephalopods, sharks and rays, seabirds, marine mammals, and more (NOAA 2022c). Oceanic whitetip shark populations have drastically declined due largely to fishing mortality and are continuing to decline in most areas. This shark has a low reproductive output, making it vulnerable to population decreases (NMFS 2018c).

#### 3.6.1.5 Scalloped Hammerhead Shark (*Sphyrna lewini*)

The scalloped hammerhead shark inhabits warm temperate and tropical waters (Maguire et al. 2006; Miller et al. 2014). It occurs in coastal and estuarine waters, but also inhabits open water over continental and insular shelves, as well as deeper waters, with depths up to 1000 m (Miller et al. 2014). Reproduction occurs annually, with a gestation time of 9–12 months (Florida Museum 2021). Females move inshore to give birth to litters of 1–41 pups (Miller et al. 2014). The scalloped hammerhead shark is very mobile and partly migratory (Maguire et al. 2006), traveling distances up to 1941 km between aggregations of food sources (Bessudo et al. 2011), eventually returning to its original habitat, displaying site fidelity (Miller et al. 2014). Juveniles and adults can be solitary or travel in pairs; they also school in productive regions, such as over seamounts or near islands (Miller et al. 2014).

### 3.6.2 Marine Invertebrates of Conservation Concern

#### 3.6.2.1 Queen Conch (*Strombus gigas*)

Adult and juvenile queen conch are herbivorous and inhabit clear waters in the Caribbean and Gulf of Mexico to ~40 m deep, very rarely up to 60 m (Stoner 1997). However, planktonic larvae occur in water up to 100 m deep, typically in the upper water column above the thermocline and within the top 5 m in calm conditions (Stoner 1997). The reproductive period for queen conch is variable but can occur year-round. Analysis of spawning activity at two sites off the Yucatán Peninsula showed reproductively active queen conch for 6- and 12-month periods (Aldana Aranda et al. 2014). Larval density plays a very important part in juvenile recruitment in nursery areas and to the population overall, and larvae may travel long distances (Stoner et al. 1996). Larval production in Mexico and the western Caribbean support the Florida queen conch population, primarily traveling via the Florida Current (Stoner et al. 1996). Hence, depending on currents, queen conch larvae could occur within the survey areas throughout the year.

### 3.6.3 Essential Fish Habitat

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 2002). The *Magnuson Stevens Fishery Conservation and Management Act* (16 U.S.C.§1801–1882) established Regional Fishery Management Councils and mandated that Fishery Management Plans (FMPs) be developed to manage exploited fish and invertebrate species responsibly in federal waters of the U.S. When Congress reauthorized the act in 1996 as the *Sustainable Fisheries Act*, several reforms and changes were made. One change was to charge NMFS with designating and conserving EFH for species managed under existing FMPs. In the Caribbean, FMPs exist for queen conch, reef fish, corals, spiny lobster, and highly migratory species (NOAA 2020a). Reef fish include angelfish, boxfish, goatfish, groupers, grunts, jacks, parrotfish, porgies, snappers, scups, squirrelfish, surgeonfish, tilefish, triggerfish and filefish, wrasses, and other species for aquarium trade. Highly migratory species include tuna, billfish, and sharks. EFH in the U.S. Caribbean, and thus occurring within the proposed survey areas, has been designated for various lifestages of fish and invertebrates (Fig. 2) and includes all water and substrates from shore to the edge of the EEZ (CFMC 1998). Important marine and estuarine habitats identified as EFH include wetlands, salt marshes, mangroves, seagrasses, intertidal flats, the water column, and coral reefs (NOAA 2020a). EFH for reef fish, queen conch, spiny lobster, and coral includes waters from the high-water mark to the edge of the EEZ (for eggs and larvae), and substrates from the high-water mark down to 100 fathoms (for the other life stages) (NOAA 2020a). For highly migratory species, geographic areas rather than habitat types has been identified as EFH (NOAA 2020a); it covers the entire EEZ.

### 3.6.4 Habitat Areas of Particular Concern

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 2020a). There are no HAPCs within the areas where seismic data would be acquired; however, there are several HAPCs near and adjacent to the proposed survey areas for coral and reef fish (Figure 3). In Puerto Rico, there are 13 ecologically important habitats for coral and 11 for reef fish, as well as 4 spawning habitats for reef fish (Table 9). In St. Croix, there are 6 important habitats for corals and 4 for reef fish, as well as 2 spawning areas for reef fish (Table 9). In St. Thomas, there are 2 ecologically important habitats for reef fish and 2 spawning areas for reef fish (Table 9; NOAA 2020a). There are no HAPCs designated at this time for highly migratory species (NOAA 2020a).

## 3.7 Fisheries

Artisanal, recreational, and subsistence fishing take place in the waters of the proposed survey areas; industrial fishing also occurs within the EEZ of the Dominican Republic. Within the Puerto Rico EEZ, industrial fishing occurred until the early 1980s when it peaked (7700 t) and then virtually disappeared (Sea Around Us 2021). Fisheries within the EEZ of Puerto Rico as a whole have experienced a sharp decline in CPUE (catch per unit effort) since the early 1980s (García 1998; Sea Around Us 2021). According to Sea Around Us (2021), fishing catches within the Puerto Rico EEZ have dropped off quite dramatically since the early 1980s in several sectors, including artisanal fishing, bringing in ~4000 t catch in 1982 and just under 1500 t in 2018.

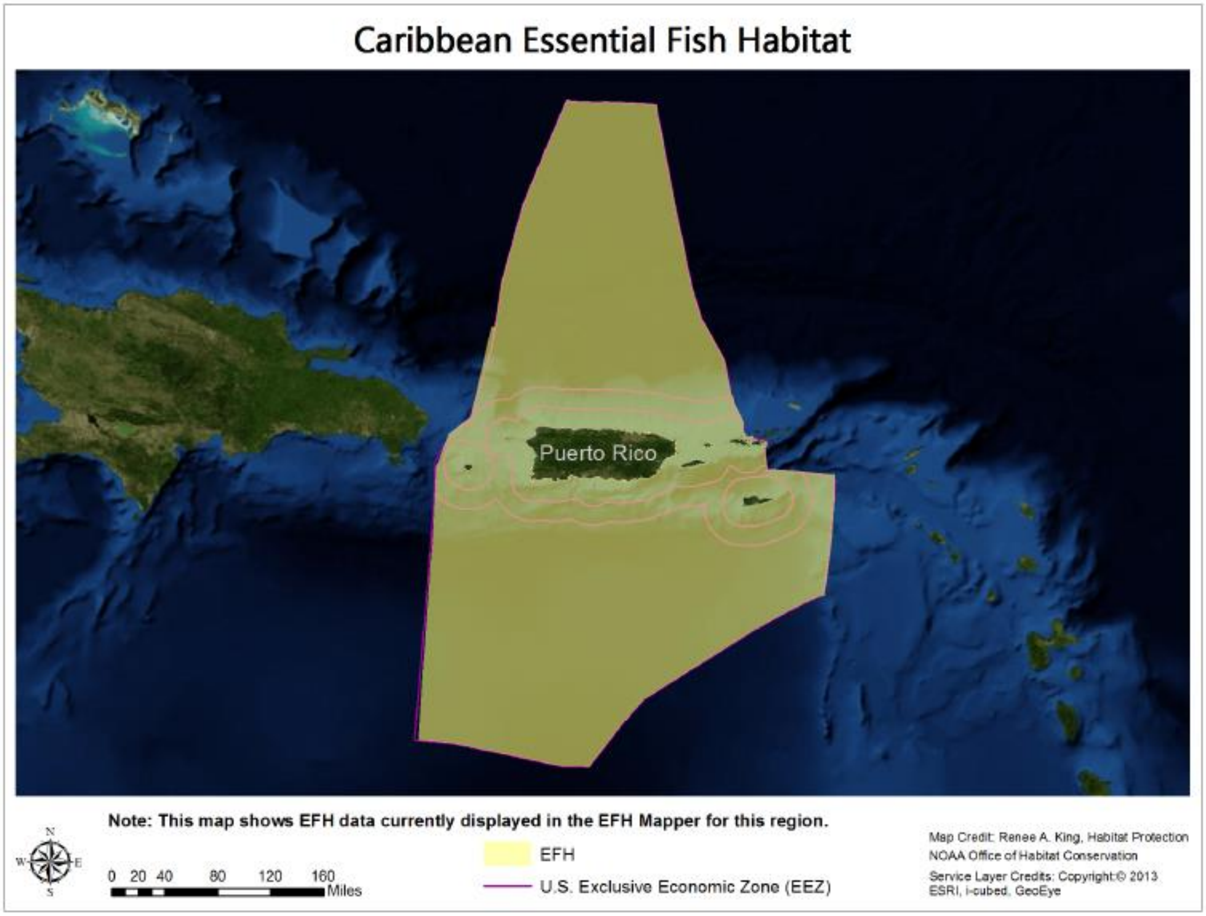


FIGURE 2. Essential fish habitat (EFH) in the U.S. Caribbean (Source: NOAA 2021a).

In contrast, recreational fishing has increased over the years, bringing in almost as much catch weight as artisanal fishing (Sea Around Us 2021). As the majority of the survey areas is located within the EEZ of Puerto Rico, fisheries for that region are detailed in Section 3.7.1 and 3.7.2. Fishing in the EEZs of the U.S. and British Virgin Islands and the Dominican Republic are summarized briefly below.

In the U.S. Virgin Islands EEZ, the total catch has decreased over the last 15 years, with a catch of ~340 t in 2018 (Sea Around Us 2021). The majority (~70%) of landed catch in 2018 was in the artisanal fishery; there was no industrial fishery in 2018. Caribbean spiny lobster made up 40 t of the catch in 2018; 'other' species made up the majority of the catch. In the British Virgin Islands EEZ, landings have significantly increased since the 1950s, from a total catch of 740 t in 1950 to a total catch of 4330 t in 2018; yellowtail snapper made up ~30% of the catch in 2018 (Sea Around Us 2021). Most of the fishing effort is by artisanal fishers (76%), followed by subsistence fishers (21%); there were no industrial fisheries in 2018. In the Dominican Republic EEZ, the catch has increased since the 1950s and has leveled off since the early 2000s at ~50,000 t per year (Sea Around Us 2021). In 2018, approximately half the catch was artisanal and half the catch was recreational, with snappers, grunts, sweetlips, and bonnetmouths making up some of the greatest catches in weight.

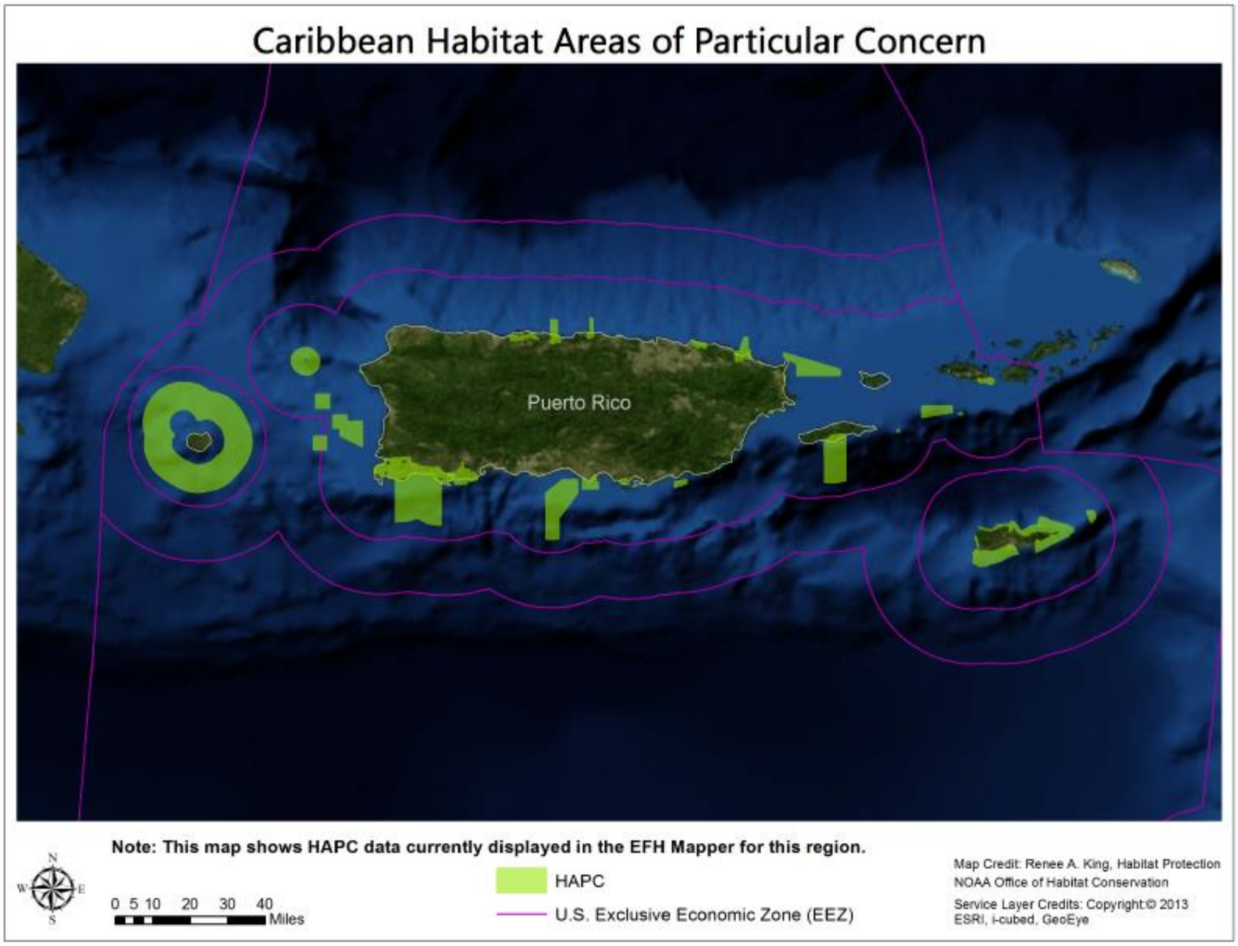


FIGURE 3. Caribbean habitat areas of particular concern or HAPC (Source: NOAA 2021b).

### 3.7.1 Commercial Fisheries

As most fishing occurs on the Puerto Rico shelf, it is impractical to use large nets and gear due to the complex coral reef habitats and other ecosystems (DoN 2002; Schärer-Umpierre et al. 2014). As such, fishermen rely on their ecological knowledge and must adapt their methods across seasons and habitats (Garcia-Quijano 2007). Commercial fisheries are not run by large industrial companies but instead owned and operated by locals (Garcia-Quijano 2007). There was, at one point, local government incentives throughout the Caribbean islands to develop industrialized commercial fleets, but ultimately fisheries are still mostly confined to the shelf (Schärer-Umpierre et al. 2014).

The fishing industry in Puerto Rico generally targets local markets for sales, rather than exportation (Schärer-Umpierre et al. 2014). It involves ~2000 vessels which tend to be less than 12 m in length with small harvests (DoN 2002; Schärer-Umpierre et al. 2014). Since the 1970's, the number of fishermen has dropped by 45%, with ~1500 fishers in Puerto Rico in 2011 (Schärer-Umpierre et al. 2014). From 1972–1982, the industrial sector had three major peaks bringing in upwards of $205 million USD a year until 1983 when it disappeared (Sea Around Us 2021). Local commercial fishery values were much lower, but remained more consistent, staying around $3 million throughout the 1960's and 1970's until dropping down to just over $1.5 million in the early 1980's (Sea Around Us 2021).

TABLE 9. Habitat areas of particular concern (HAPC) in the U.S. Caribbean (Source: NOAA 2020a).

| **Country** | **Coral Ecologically Important Habitat** | **Reef Fish Ecologically Important Habitat** | **Reef Fish Spawning Habitat** |
|---|---|---|---|
| Puerto Rico | Luis Peña Channel, Culebra | Hacienda la Esperanza, Manití | Tourmaline Bank/Buoy 8 |
| | Mona/Monito | Bajuras and Tiberones, Isabela | Abrir La Sierra Bank/Buoy 6 |
| | La Parguera, Lajas | Cabezas de San Juan, Fajardo | Bajo de Sico |
| | Caja de Muertos, Ponce | JOBANNERR, Jobos Bay | Vieques, El Seco |
| | Tourmaline Reef | Bioluminescent Bays, Vieques | |
| | Guánica State Forest | Boquerón State Forest | |
| | Punta Petrona, Santa Isabel | Pantano Cibuco, Vega Baja | |
| | Ceiba State Forest | Piñones State Forest | |
| | La Cordillera, Fajardo | Río Espiritu Santo, Río Grande | |
| | Guayama Reefs | Seagrass beds of Culebra Island (nine sites designated as Resource Category 1 and two additional sites) | |
| | Steps and Tres Palmas, Rincon | Northwest Vieques seagrass west of Mosquito Pier, Vieques | |
| | Los Corchos Reef, Culebra | | |
| | Desecheo Reefs, Desecheo | | |
| St. Croix | St. Croix Coral Reef Area of Particular Concern, including the East End Marine Park | Salt River Bay National Historical Park and Ecological Preserve and Marine Reserve and Wildlife Sanctuary | Mutton snapper spawning aggregation area |
| | Buck Island Reef National Monument | Altona Lagoon | East of St. Croix (Lang Bank) |
| | South Shore Industrial Area Patch Reef and Deep Reef System | Great Pond South Shore Industrial Area | |
| | Frederiksted Reef System | Sandy Point National Wildlife Refuge | |
| | Cane Bay | | |
| | Green Cay Wildlife Refuge | | |
| St. Thomas | | Southeastern St. Thomas, including Cas Key and the mangrove lagoon in Great St. James Bay | Hind Bank Marine Conservation District |
| | | Saba Island/Perseverance Bay, including Flat Key and Black Point Reef | Grammanik Bank |

In 2018, commercial landings from the Puerto Rico EEZ totaled 1430 t and $490,000 USD (Sea Around Us 2021). Employing the majority of fishermen, the shallow water reef fishery includes snapper, grouper, grunt, and parrotfish families (DoN 2002; Garcia-Quijano 2007). However, before 1990, reef species had been overexploited due to the specific targeting of spawning aggregations and large-bodied individuals by fishermen (Schärer-Umpierre et al. 2014). In recent years, many formerly abundant species in these habitats can only be found off the insular slope (Schärer-Umpierre et al. 2014). The main methods used by commercial fishermen include handlines and traps (DoN 2002; Schärer-Umpierre et al. 2014). Additional popular species include the queen conch, common octopus (*Octopus vulgaris*), spiny lobster, and the Atlantic land crab (*Cardisoma guanhumi*) (Garcia-Quijano 2007). Mollusks such as conch are located in shallow water and almost entirely collected by scuba divers (DoN 2002).

Fishers are also able to target high value pelagic species due to the proximity of the deep water to Puerto Rico shores (DoN 2002). Due to the narrow insular shelf, some smaller pelagic species such as herring (*Clupeidae* family) appear close enough to shore such that they can be caught using beach seines (DoN 2002). Commercially important pelagic species include mackerel and tuna (*Scombroidae*), jack (*Carangidae*), dolphinfish (*Coryphaenidae*), and swordfish (*Xiphiidae*) families (Garcia-Quijano 2007). These larger species tend to be of better market quality and higher value and are typically sold either to processors or restaurants or may be exported (FAO 1993; DoN 2002). Boats tend to be larger and in addition to traps and handlines, deepwater reef fishing may use longlines, depth sounders, and trap haulers (DoN 2002). The primary gear used in pelagic fisheries is the troll line, which is responsible for the majority of deep-water harvests (Appeldoorn 1993; DoN 2002). The proposed survey areas overlap the year-round fishing grounds for most pelagic fish (see DoN 2002). Swordfish is typically targeted during November through April, but based on DoN (2002), the swordfish fishery does not overlap the location of the proposed seismic lines.

### 3.7.2 Artisanal and Recreational Fisheries

Most fishing activities currently occurring within the Puerto Rico EEZ consists of artisanal fishing operations; they are small scale, typically operator-owned and household-managed, and are low-tech using traditional methods and smaller vessels (DoN 2002; Garcia-Quijano 2007; Schärer-Umpierre 2014). Artisanal fisheries mainly take place nearshore, on the insular shelf (DoN 2002). Up until the early 1980s, subsistence fishery landings were between 150–200 t before dropping off (Sea Around Us 2021). In contrast, the recreational fishery has increased in the last 40 years with a catch of 1350 t in 2018 and bringing in more revenue than the commercial fisheries in the same year ($620,000 USD).

On the shelf, particularly off the southwest coast of Puerto Rico, García et al. (1998) reported that fishing effort was evenly split between commercial and recreational fishing. Recreational fishing gear includes line and hook, jigging, spearfishing, and fly-casting (García et al. 1998). Puerto Rico has a large recreational fleet, consisting of as many as 55,000 boats, ranging 10–14 m in length (DoN 2002; Weidner 2001). Of these, 5000 are meant to be equipped specifically for fishing pelagic species (DoN 2002). In more recent years, there has been limited interest in reef fish resulting in a shift of fishing activities toward the slope in search of pelagic species (DoN 2002). Recreational fisheries tend to occur year-round, but decrease during the winter months (DoN 2002). Billfish are the target species for Puerto Rican recreational fisheries. Non-resident billfish anglers are responsible for bringing in an estimated $4.75 million and 200+ jobs to the Puerto Rican economy (DoN 2002). Competitive billfish tournaments have grown in the area as well, regularly occurring throughout all seasons within the nearshore and offshore survey areas, but typically not off the southwestern coast during fall (DoN 2002).

## 3.8 SCUBA Diving, Shipwrecks, and other Cultural Sites

Recreational SCUBA diving occurs all around Puerto Rico and its islands, Dominican Republic, and U.S. and British Virgin Islands, where numerous dive centers offer chartered services to popular dive sites (Dive Advisor 2021; Dive Buddy 2021; PADI 2021). Recreational diving occurs year-round near Puerto Rico and is an important component of local reef-based tourism activities, with nearly $1 million in revenue for SCUBA and snorkel equipment rental alone during 2017 (Leeworthy et al. 2018). Locations of dive sites near the proposed survey area in the Caribbean Sea are shown in Figure 4, and sites within 50 km of proposed transect lines are provided in Table 10. Dive sites within 15 km of the proposed transect lines are summarized below; all of which occur off the southern coast of Puerto Rico.

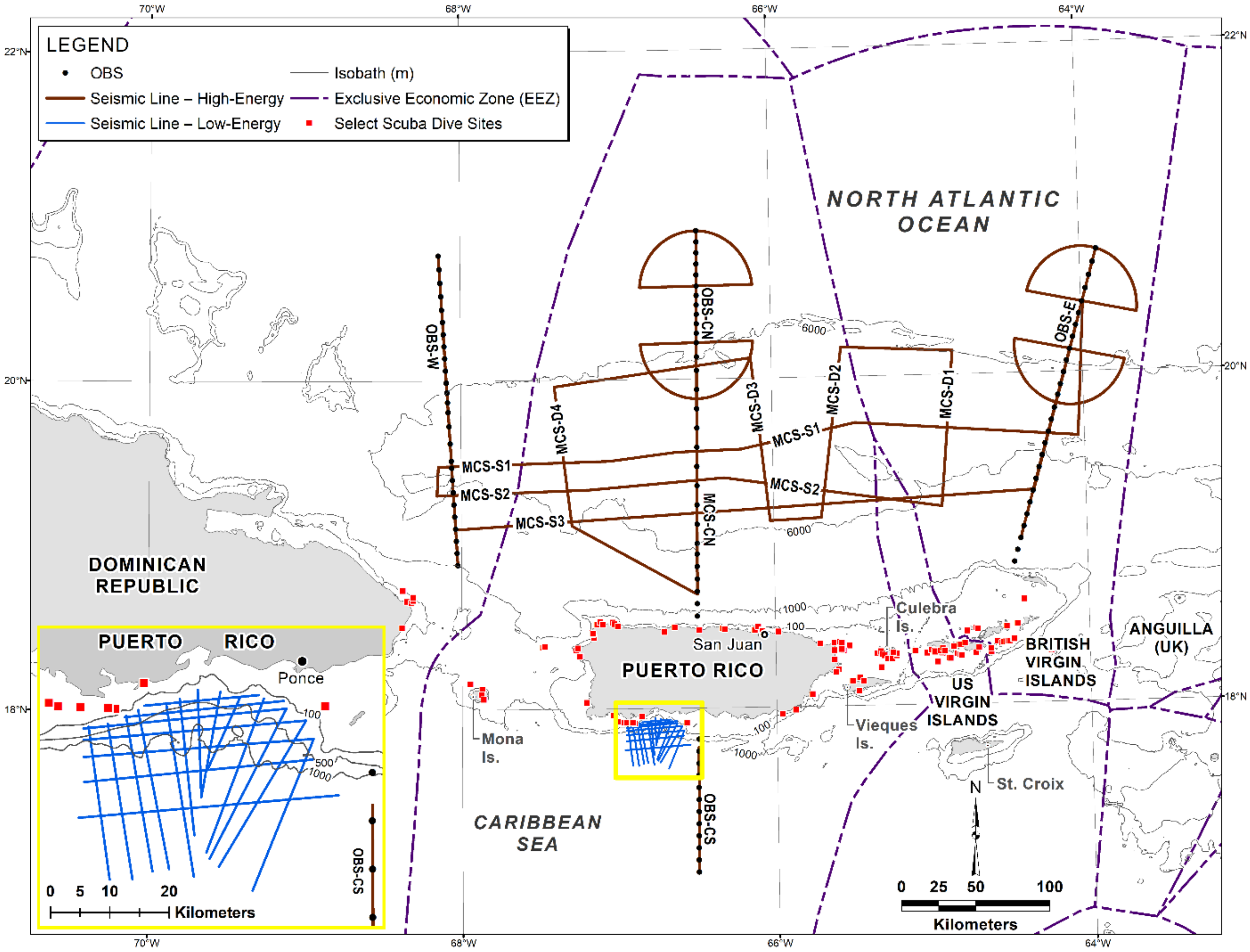


FIGURE 4. Location of SCUBA diving sites in Puerto Rico, eastern Dominican Republic, and Virgin Islands (Source: Dive Buddy 2021; PADI 2021).

Table 10. SCUBA diving sites within 50 km of the proposed seismic survey lines (Source: Dive Buddy 2021; PADI 2021).

| Area | Dive Site | Latitude | Longitude | Location Relative to Survey Areas |
|---|---|---|---|---|
| Puerto Rico | B-29 Bomber Wreck | 18.51549 | -67.13676 | ≤50 km |
| Puerto Rico | Snorkeling Reef | 18.04077 | -67.20783 | ≤50 km |
| Puerto Rico | Ambar Wreck | 18.53053 | -67.11891 | ≤50 km |
| Puerto Rico | Shacks Blue Hole | 18.51616 | -67.10039 | ≤50 km |
| Puerto Rico | Shacks Beach | 18.515891 | -67.100179 | ≤50 km |
| Puerto Rico | Fishing Village | 18.526491 | -67.0385742 | ≤50 km |
| Puerto Rico | The Trench | 18.5 | -66.44999 | ≤25 km |
| Puerto Rico | Shucks Beach | 18.5160745 | -67.0275878 | ≤50 km |
| Puerto Rico | Aguadilla Reef | 18.500447 | -67.005615 | ≤50 km |
| Puerto Rico | Cueva del Indio. Arecibo | 18.463978 | -66.708984 | ≤50 km |
| Puerto Rico | La Cueva del Indio | 18.493152 | -66.642627 | ≤50 km |
| Puerto Rico | Mar Chiquita | 18.474007 | -66.4852559 | ≤25 km |
| Puerto Rico | Cerro Gordo | 18.482809 | -66.341406 | ≤50 km |
| Puerto Rico | La Reja | 18.484687 | -66.336431 | ≤50 km |
| Puerto Rico | La Trampa de Buzo (Carlos Playground) | 18.478767 | -66.324714 | ≤50 km |
| Puerto Rico | Isla de Cabras | 18.471685 | -66.132406 | ≤50 km |
| Puerto Rico | Escambro | 18.490028 | -66.1102294 | ≤50 km |
| Puerto Rico | Figure 8 Reef | 18.466665 | -66.086196 | ≤50 km |
| Puerto Rico | Horseshoe Reef | 18.46642 | -66.086068 | ≤50 km |
| Puerto Rico | Inner Reef | 18.465952 | -66.086475 | ≤50 km |
| Puerto Rico | Escambron | 18.465927 | -66.086428 | ≤50 km |
| Puerto Rico | Puerto Rico | 17.913409 | -66.571655 | **≤15 km** |
| Puerto Rico | Bahia Ballenas | 17.951708 | -66.858587 | **≤15 km** |
| Puerto Rico | Dominican Rock | 17.912674 | -66.905021 | **≤15 km** |
| Puerto Rico | Fallen Rock | 17.914296 | -66.916194 | **≤15 km** |
| Puerto Rico | Efra | 17.915859 | -66.960382 | **≤15 km** |
| Puerto Rico | Black Wall | 17.917656 | -66.996173 | **≤15 km** |
| Puerto Rico | Parguera's Wall | 17.923209 | -67.010421 | **≤15 km** |
| Puerto Rico | Motor Reef, Pratt & Whitney R-1830-92 | 17.963057 | -67.033081 | **≤15 km** |
| Puerto Rico | Mata De La Gata Island | 17.961506 | -67.036406 | **≤15 km** |
| Puerto Rico | Enrique | 17.960457 | -67.038065 | **≤15 km** |
| Dominican Republic | Paradise | 18.721698 | -68.384742 | ≤50 km |
| Dominican Republic | Park Reef | 18.729501 | -68.379249 | ≤50 km |
| Dominican Republic | Rondana | 18.7256 | -68.376502 | ≤50 km |
| Dominican Republic | Explorer | 18.660929 | -68.351526 | ≤50 km |
| Dominican Republic | Deep Blue | 18.651786 | -68.321246 | ≤50 km |
| Dominican Republic | Patricia Wreck | 18.666412 | -68.311271 | ≤50 km |
| Dominican Republic | Channel | 18.687228 | -68.308525 | ≤50 km |
| British Virgin Islands | Chikuzen Wreck | 18.627844 | -64.413204 | ≤50 km |

The Puerto Rico dive site is located off southern Puerto Rico, east of the northeastern portion of the proposed USGS transect lines. This site hosts a variety of marine life, such as eel, angelfish, and crabs, and has a maximum depth of 30 m (Dive Buddy 2021). Bahia Ballenas is located north of the northwestern portion of the proposed USGS transect lines south of Puerto Rico, near Guanica (Dive Buddy 2021).

Dominican Rock is a deeper dive site, with a maximum depth of 40 m, located northwest of the proposed USGS transect lines. It features a sea wall with a thriving benthic community near the wall ledge (Dive Buddy 2021). The Fallen Rock dive site, also northwest of the proposed USGS transect lines, is one of the most popular sites for advanced divers off southwestern Puerto Rico, featuring a coral-covered boulder and thriving reef community at maximum depths of 37 m (Dive Buddy 2021). Efra features a drop off and sea wall hosting an abundance of marine life and corals; it has a maximum dive depth of 46 m and is northwest of the proposed USGS transect lines (Dive Buddy 2021). Black Wall, also northwest of the proposed USGS transect lines, has a maximum depth of 40 m, and features black and gorgonian corals, sponges, and a variety of associated sea life (Dive Buddy 2021). At a maximum depth of 37 m and located northwest of the proposed USGS transect lines, Parguera's Wall is a popular site that features optimal diving conditions year-round and high benthic biodiversity (Dive Buddy 2021). The Motor Reef, Pratt & Whitney R-1830-92 dive site is located northwest of the proposed USGS transect lines and includes wreckage from a downed Pratt & Whitney R-1830-92 U.S. Navy or Army aircraft at a maximum depth of 18 m (Dive Buddy 2021). The Mata De La Gata Island dive site is located among the Isla Mata La Gata islands, northwest of the proposed USGS transect lines (Dive Buddy 2021). The Enrique site is also located near Isla Mata La Gata, northwest of the proposed USGS transect lines; it has a maximum depth of 18 m (Dive Buddy 2021).

There are numerous shipwrecks and underwater obstructions near Puerto Rico and the U.S. and British Virgin Islands, mainly located coastally or otherwise nearshore (NOAA 2020b). Figure 5 shows wrecks and obstructions near the proposed survey areas, and Table 11 lists those within 50 km of the proposed transect lines. Nine obstructions are located within 15 km of the proposed transect lines, including a submerged chain link fence, metal plates and pipes, wood piles, and several unidentified objects. Eighteen unidentified shipwrecks also occur within 15 km of the proposed transect lines. These 27 shipwrecks and obstructions are located off Puerto Rico's southwest coast, near the proposed USGS transect lines.

Puerto Rico features several underwater archeological sites, including three Spanish-American War and three U.S. military-related sites (NPS 2021). Of the former, the *Antonio López* ran aground on a reef west of San Juan, southeast of proposed transect lines MCS-D4 and MCS-CN, after being shelled by the U.S. Navy and was designated a National Historic Landmark in 1997; and the *Manuela* and *Cristóbal Colón* were purposely sunk to obstruct entry into the San Juan Harbor channel (NPS 2021). During 2021, the *Manuela* and *Cristóbal* were removed from the harbor and positioned near the *Antonio López* (NPA 2021). The U.S. military sites include a Boeing B-29 that likely ditched off Aguadilla due to mechanical issues in 1945, located off northwestern Puerto Rico and within 50 km of the proposed MCS-D4 transect line; a patrol craft that likely sank in 1943 (location unclear); and an aircraft wreckage on Motor Reef, off southwest Puerto Rico and northwest of the proposed USGS transect lines (NPS 2021). These submerged archaeological sites are maintained by Puerto Rico's Council for the Conservation and Study of Underwater Archaeological Sites and Resources and protected by the *Act for the Protection, Conservation and Study of the Underwater Archaeological Sites and Resources* (NPS 2021).

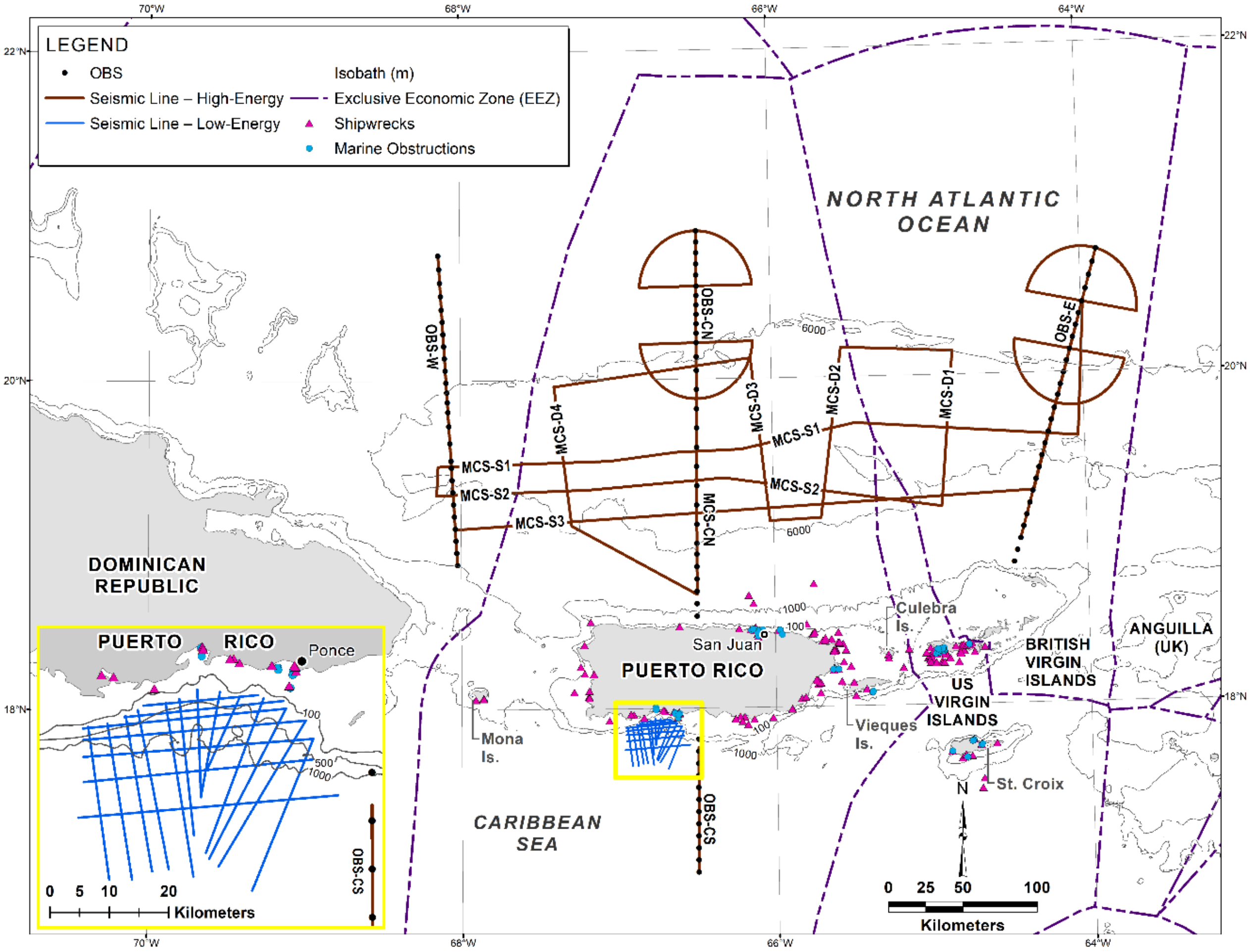


FIGURE 5. Location of shipwrecks and obstructions near the proposed survey areas (Source: NOAA 2020b).

Table 11. Shipwrecks and obstructions within 50 km of the proposed survey transect lines in the Northwest Atlantic Ocean (Source: NOAA 2020b). All are within the Puerto Rico EEZ.

| Wreck/Obstruction Name | Latitude (N) | Longitude (W) | Location Relative to Survey Areas |
|---|---|---|---|
| Obstruction | 17.963672 | -66.619553 | **≤15 km** |
| Obstruction | 18.004511 | -66.766511 | **≤15 km** |
| Obstruction | 17.991619 | -66.765986 | **≤15 km** |
| Obstruction | 17.941867 | -66.625753 | **≤15 km** |
| Obstruction | 17.967397 | -66.620514 | **≤15 km** |
| Obstruction | 17.972775 | -66.644908 | **≤15 km** |
| Obstruction | 17.969492 | -66.644722 | **≤15 km** |
| Obstruction | 17.966997 | -66.616647 | **≤15 km** |
| Obstruction | 17.961333 | -66.621789 | **≤15 km** |
| Obstruction | 18.472944 | -66.128278 | ≤ 50 km |
| Obstruction | 18.458864 | -66.116197 | ≤ 50 km |
| Obstruction | 18.469639 | -66.152389 | ≤ 50 km |
| Obstruction | 18.474711 | -66.140606 | ≤ 50 km |
| Unknown | 17.897069 | -66.181119 | ≤ 50 km |
| Unknown | 17.932192 | -66.260378 | ≤ 50 km |
| Unknown | 17.945089 | -66.627319 | **≤15 km** |
| Unknown | 17.973667 | -66.616942 | **≤15 km** |
| Unknown | 17.966914 | -66.616289 | **≤15 km** |
| Unknown | 17.931778 | -66.259333 | ≤ 50 km |
| Unknown | 18.472306 | -66.139056 | ≤ 50 km |
| Unknown | 18.4715 | -66.130611 | ≤ 50 km |
| Unknown | 18.481217 | -66.132017 | ≤ 50 km |
| Unknown | 18.484647 | -66.125219 | ≤ 50 km |
| Unknown | 18.472306 | -66.156417 | ≤ 50 km |
| Transcaribbean | 18.472972 | -66.132914 | ≤ 50 km |
| Prock Barge 19 | 18.46925 | -66.132861 | ≤ 50 km |
| Duo | 18.471611 | -66.132942 | ≤ 50 km |
| Antonio Lopez | 18.478583 | -66.231083 | ≤ 50 km |
| Carl O | 18.468417 | -66.132389 | ≤ 50 km |
| Caribe | 18.681325 | -66.166278 | ≤ 50 km |
| Shipwreck (x 39) | Not provided | Not provided | ≤ 50 km |
| Shipwreck (x 15) | Not provided | Not provided | **≤ 15 km** |

## 3.9 Terrestrial ESA-Listed Species

The USFWS Information for Planning and Consultation (IPaC) tool was used to determine potential overlap with terrestrial ESA-listed species and critical habitat, and the land seismometer locations. When entering the location of the study area, buffers of 250-m were used around each site to allow for variation in deployment locations in the field. Eight ESA-listed species could occur near the land seismometer deployments, including the *endangered* Puerto Rican broad-winged hawk (*Buteo platypterus brunnescens*), Puerto Rico nightjar (*Caprimulgus noctitherus*), Puerto Rican parrot (*Amazona vittata*), Puerto Rican sharp-shinned hawk (*Accipiter striatus venator*), Puerto Rican boa (*Epicrates inornatus*), and the flowering plans Palo De Ramon (*Banara vanderbiltii*), Palo de Rosa (*Ottoschulzia rhodoxylon*), and West Indian walnut (nogal; *Juglans jamaicensis*). As none of the sites are located on beaches, no sea turtle nesting sites would be disturbed. Additionally, there is no critical habitat near the proposed land seismometer sites. Potential effects of the proposed activities on these species is discussed in 4.1.6.

# 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 µPa$_{\text{rms}}$ is also provided.

#### 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 (Southall et al. 2007; Le Prell 2012). Physical damage to a mammal's hearing apparatus can occur if it is exposed to sound impulses that have very high peak pressures, especially if the impulses have very short rise times (e.g., Morell et al. 2017). However, the impulsive nature of sound is range-dependent (Hastie et al. 2019; Martin et al. 2020), and may become less harmful over distance from the source (Hastie et al. 2019). 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; Houser 2021). 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., Nieukirk 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. Kyhn et al. (2019) reported that baleen whales and seals were likely masked over an extended period of time during four concurrent seismic surveys in Baffin Bay, Greenland. Nieukirk et al. (2012), Blackwell et al. (2013), and Dunlop (2018) also 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., Nieukirk 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; Thode et al. 2020; Fernandez-Betelu et al. 2021). 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, 2018). 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). Kastelein et al. (2019a) surmized that if disturbance by noise would displace harbor porpoises from a feeding area or otherwise impair foraging ability for a short period of time (e.g., 1 day), they would be able to compensate by increasing their food consumption following the disturbance. Some studies have attempted modeling to assess consequences of effects from underwater noise at the population level; this has proven to be complicated by numerous factors including variability in responses between individuals (e.g., New et al. 2013b; 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; Dunlop et al. 2021; Gallagher et al. 2021; McHuron et al. 2021; Mortensen et al. 2021).

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; many data gaps remain where exposure criteria are concerned (Southall 2021).

### *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). Kavanagh et al. (2019) analyzed more than 8000 hr of cetacean survey data in the northeastern Atlantic Ocean to determine the effects of the seismic surveys on cetaceans. They found that sighting rates of baleen whales were significantly lower during seismic surveys compared with control surveys.

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 $in^3$ 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 in$^3$, 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, 2020). Overall, the results showed that humpbacks were more likely to avoid active small airgun sources (20 and 140 in$^3$) within 3 km and received levels of at least 140 dB re 1 µPa$^2 \cdot$ s (Dunlop et al. 2017a). Responses to ramp up and use of a large 3130 in$^3$ array elicited greater behavioral changes in humpbacks when compared with small arrays (Dunlop et al. 2016c). Humpbacks deviated from their southbound migration when they were within 4 km of the active large airgun source, where received levels were >130 dB re 1 µPa$^2 \cdot$ s (Dunlop et al. 2017b, 2018). These results are consistent with earlier studies (e.g., McCauley et al. 2000). Dunlop et al. (2020) found that humpback whales reduce their social interactions at greater distances and lower received levels than regulated by current mitigation practices.

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).

Matthews and Parks (2021) summarized the known responses of *right whales* to sounds; however, 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 µPa; at SPLs <108 dB re 1 µPa, 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 $\text{CSEL}_{10\text{-min}}$ (cumulative SEL over a 10-min period) of ~94 dB re 1 µPa$^2 \cdot$ s, decreased at $\text{CSEL}_{10\text{-min}}$ >127 dB re 1 µPa$^2 \cdot$ s, and whales were nearly silent at $\text{CSEL}_{10\text{-min}}$ >160 dB re 1 µPa$^2 \cdot$ s. Thode et al. (2020) reported similar changes in bowhead whale vocalizations when data were analyzed for the period 2008–2014. 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 two-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 $\mu\text{Pa}_{\text{rms}}$ (Johnson et al. 2007; Nowacek et al. 2012, 2013b). In contrast, despite rigorous monitoring and mitigation measures during multiple seismic surveys in 2015 (Aerts et al. 2022; Rutenko et al. 2022), data collected during a program with multiple seismic surveys in 2015 showed some displacement of gray whales from the feeding area and responses to lower sound levels than expected (Gailey et al. 2017, 2022a,b; Sychenko et al. 2017). These findings demonstrate the variability in marine mammal response, in this case foraging gray whale, to seismic survey sound and the need for robust data collected over multiple seasons. A comparison of stochastic dynamic programming (SDP) model predictions relative to the foraging gray whale empirical data collected in 2015 further highlights the need for robust data collection including fine-scale temporal and distributional data on prey as well as comprehensive data on reproductive success of gray whales (Schwarz et al. 2022). The SDP model predictions generally agreed with empirical data but were limited by data gaps for some model parameters.

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

Various species of *Balaenoptera* (blue, sei, fin, and minke whales) have occasionally been seen in areas ensonified 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 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. However, Heide-Jørgensen et al. (2021) did report avoidance reaction at distances >11 km from an active seismic vessel, as well as an increase in travel speed and changes in direction at distances up to 24 km from a seismic source. No long-term effects were reported. Tervo et al. (2021) reported that narwhal buzzing rates decreased in response to concurrent ship noise and airgun pulses (being 50% at 12 km from ship), and that the whales discontinued to forage at 7–8 km from the vessel, and that exposure effects could still be detected >40 km from the vessel.

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 $\mu Pa^2 \cdot s$). 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). Similar avoidance behavior and/or decreases in echolocation signals during 3-D seismic operations were reported for harbor porpoise in the North Sea (Sarnocińska et al. 2020). 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 $\mu Pa_{0\text{-peak}}$. 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 $in^3$ airgun for 1 min at 2–3 s intervals at ranges of 420–690 m and levels of 135–147 dB $\mu Pa^2 \cdot s$. One porpoise moved away from the sound source but returned to natural movement patters 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 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; Tyack and Thomas 2019).

### *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 gray or harbor seals during seismic vs. non-seismic periods (Stone 2015). Lalas and McConnell (2015) made observations of New Zealand fur seals from a seismic vessel operating a 3090 in$^3$ 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 $\mu Pa_{peak}$. These observations were made during ~150 h of vessel-based monitoring from a seismic vessel operating an airgun array (13 airguns, 2440 in$^3$) 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, 2018, 2019a,b, 2020a,b,c,d,e,f, 2021a,b, 2022; 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 µPa2 · 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 µPa 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 $\text{SEL}_{\text{cum}}$ of 188 and 191 µPa$^2$ · 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. 2018; Finneran 2020; Kastelein et al. 2020g).

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. Based on studies that exposed harbor porpoises to one-sixth-octave noise bands ranging from 1–88.4 kHz, Kastelein et al. (2019c,d, 2020d,e,f) noted that susceptibility to TTS increases with an increase in sound less than 6.5 kHz but declines with an increase in frequency above 6.5 kHz. At a noise band centered at 0.5 kHz (near the lower range of hearing), the SEL required to elicit a 6 dB TTS is higher than that required at frequencies of 1–88.4 kHz (Kastelein et al. 2021a). 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 µPa 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 $L_{\text{eq-fast}}$ (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. 2013a). 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 µPa; 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 µPa 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 µPa for 1 h induced a 44 dB TTS. A maximum TTS >45 dB was elicited from a harbor seal exposed to 32 kHz at 191 dB SEL (Kastelein et al. 2020c). 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 µPa, the onset of PTS would require a level of at least 22 dB above the TTS onset (Kastelein et al. 2013c). Harbor seals appear to be equally susceptible to incurring TTS when exposed to sounds from 2.5–40 kHz (Kastelein et al. 2020a,b), but at frequencies of 2 kHz or lower, a higher SEL was required to elicit the same TTS (Kastelein et al. 2020c). Harbor seals may be able to decrease their exposure to underwater sound by swimming just below the surface where sound levels are typically lower than at depth (Kastelein et al. 2018). 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 µPa; no low-frequency TTS was observed. Similarly, no TTS was measured when a bearded seal was exposed to a single airgun pulse with an unweighted SEL of 185 dB and an SPL of 207 dB; however, TTS was elicited at 400 Hz when exposed to four to ten consecutive pulses with a cumulative unweighted SEL of 191–195 dB, and a weighted SEL of 167–171 dB (Sills et al. 2020). Kastelein et al. (2021b) found that susceptibility of TTS of California sea lions exposed to one-sixth-octave noise bands centered at 2, 4, and 8 kHz is similar to that of harbor seals, but at 16 kHz, California sea lion haring is less susceptible to TTS than harbor seals (Kastelein et al. 2022).

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. SPLs for impulsive sounds are generally lower just below the water surface, and seals swimming near the surface are likely to be exposed to lower sound levels than when swimming at depth (Kastelein et al. 2018). However, the underwater sound hearing sensitivity for seals is the same near the surface and at depth (Kastelein et al. 2018). 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 noise exposure criteria for marine mammals that were released by NMFS (2016a, 2018) 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. Morell et al. (2020) describe new methodology that visualizes scars in the cochlea to detect hearing loss in stranded marine mammals.

Since 1991, there have been 72 Marine Mammal Unusual Mortality Events (UME) in the U.S. (NOAA 2023). In a hearing to examine the Bureau of Ocean Energy Management’s 2017–2022 OCS Oil and Gas Leasing Program (https://www.energy.senate.gov/public/index.cfm/2016/5/hearing-is-examine-the-bureau-of-ocean-energy-management-s-2017-2022-ocs-oil-and-gas-leasing-program), 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. Similarly, the large whale UME Core Team found that seismic testing did not contribute to the 2015 UME involving humpbacks and fin whales from Alaska to B.C. (Savage 2017).

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 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 µPa SPL (peak) and 204 dB re 1 $\mu Pa^2 \cdot s$ $SEL_{cum}$ (weighted) for PTS; and 226 dB peak and 189 dB weighted SEL for TTS (DoN 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. A leading scientific expert 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).

During a recent study, group vocal periods (GVP) were used as proxies to assess foraging behavior and use of habitat by Cuvier's beaked whales during multibeam mapping with a 12 kHz MBES in southern California (Varghese et al. 2021). The studies found that there was no significant difference between GVP during multibeam mapping and non-exposure periods, suggesting that the level of foraging and habitat use likely did not change during multibeam mapping. During an analogous study assessing naval sonar (McCarthy et al. 2011), significantly fewer GVPs were recorded during sonar transmission (McCarthy et al. 2011; Varghese et al. 2020).

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 µPa. 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).

Frankel and Stein (2020) reported that gray whales responded to a 21–25 kHz active sonar by deflecting 1–2 km away from the sound. Sperm whales exposed to sounds from a low-frequency 1–2 kHz sonar transitioned to non-foraging and non-resting states, but did not respond to 4.7–5.1 kHz or 6–7 kHz sonar signals (Isojunno et al. 2016). 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).

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.

Despite the aforementioned information that has recently become available, this Draft 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 areas. 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; Kyhn et al. 2019; Landrø and Langhammer 2020); 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 have also been shown to 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; Popov et al. 2020; Branstetter and Sills 2022). 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; Fornet et al. 2018). 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.

In addition to masking, Erbe et al. (2019) noted that ship noise can elicit physical and behavioral responses in marine mammals, as well as stress. However, shipping noise is typically not thought to produce sounds capable of eliciting hearing damage. Trigg et al. (2020) noted that gray seals are not at risk of TTS from shipping noise, based on modeling. 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 rorquals (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) and killer whales (Williams et al. 2021). 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 (Pirotta 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 vessels speeds were below 12.5 kt. 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; two dedicated observers 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 for high energy surveys (unless the system and back-up systems are temporarily damaged during operations); shut downs when marine mammals are detected in or about to enter the designated EZ; and power downs (or if necessary shut downs) when ESA-listed sea turtles and seabirds (diving/foraging) are detected in or about to enter 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. In addition, mitigation measures to reduce the potential of bird strandings on the vessel include downward-pointing deck lighting and curtains/shades on cabin windows.

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 Marine Mammals 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. Consistent with past similar proposed actions, NSF has followed the NOAA *Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing* for estimating Level A takes. Although NMFS may issue Level A takes for the remote possibility of low-level physiological effects, because of the characteristics of the proposed activities and the proposed monitoring and mitigation measures, in addition to the general avoidance by marine mammals of loud sounds, injurious takes would not be expected, in particular during the low-energy surveys. (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 sound levels for the high-energy surveys and Level B sound levels for the high- and low-energy surveys, and we present estimates of the numbers of marine mammals that could be affected during the proposed seismic surveys (additional details are provided in Appendix B). The estimates are based on consideration of the number of marine mammals that could be harassed by sound (Level B takes) produced by the seismic surveys off Puerto Rico in the Northwest Atlantic Ocean.

The numbers of marine mammals that could be exposed to airgun sounds with received levels

≥160 dB re 1 µ$\text{Pa}_{\text{rms}}$ (Level B) on one or more occasions have been estimated using a method recommended 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 (~222 km for OBS lines and 182 km for MCS lines during the high-energy surveys; ~200 km for the low-energy surveys) that is roughly similar to that of the entire surveys. 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 Level B and PTS threshold buffers) around each line. The ensonified areas, increased by 25%, were then multiplied by the number of survey days (6 OBS days and 15 MCS days for the high-energy surveys; 3 days for the low-energy surveys). This is equivalent to adding an additional 25% to the proposed line km (Appendix B). 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.

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.

We used habitat-based stratified marine mammal densities for the North Atlantic for the U.S. Navy Atlantic Fleet Testing and Training (AFTT) Area from Roberts et al. (2023) for any time of the year, when available. The habitat-based density models consisted of 10 km x 10 km grid cells. Densities in the grid cells for the AFTT Area south of 21°N were averaged per month within each of two water depth categories (intermediate and deep); for most species, only annual densities were available for averaging within the two water depth categories. Sea turtle densities were derived from outputs of the model described by Putman et al. (2019). The model was used to estimate the densities of green and loggerhead sea turtles within the survey areas in October–November for the years 2010–2017. Densities for leatherback turtles were derived from those reported for the Florida current (Bovery and Wyneken 2015). No densities were available for hawksbill or olive ridley sea turtles.

Table 12 shows estimated densities for cetacean and sea turtle species that could potentially occur in the proposed survey areas. For most species, the average monthly densities were the same throughout the year; densities for fin whale, sei whale, humpback whale, and Atlantic white-sided dolphin varied by month, so the highest monthly densities are shown. Densities for harbor porpoise, Atlantic white-sided dolphin, and white-beaked dolphin have been included here for the sake of completeness, even though these species are not likely to be encountered in the proposed survey areas. There is uncertainty about the representativeness of the data and the assumptions used to estimate exposures below. Thus, for some species, the densities derived from the abundance models described above may not precisely represent the densities that would be encountered during the proposed seismic surveys.

TABLE 12. Annual average densities of marine mammals and fall densities for sea turtles off Puerto Rico, Northwest Atlantic Ocean. Densities in bold were used to estimate takes for sea turtles.

| | **Density (#/km$^2$) in Survey Area** | | **Density (#/km$^2$) (Putman et al. 2019)** | **Density (#/km$^2$) (Bovery and Wyneken 2015)** |
|---|---|---|---|---|
| | *Intermediate Water Depth (100-1000 m)* | *Deep Water (>1000 m)* | *Any* | *Any* |
| **LF Cetaceans** | | | | |
| Humpback whale[1] | 0.004739 | 0.003748 | | |
| Minke whale | 0.000184 | 0.000835 | | |
| Bryde's whale | 0.000085 | 0.000088 | | |
| Fin whale[2] | 0.000013 | 0.000006 | | |
| Sei whale[3] | 0.000319 | 0.000319 | | |
| Blue whale | 0.000020 | 0.000020 | | |
| **MF Cetaceans** | | | | |
| Sperm whale | 0.005312 | 0.006623 | | |
| Beaked whales (all) | 0.009887 | 0.007392 | | |
| Cuvier's beaked whale | | | | |
| Blaineville's beaked whale | | | | |
| Gervais' beaked whale | | | | |
| True's beaked whale | | | | |
| Risso's dolphin | 0.005193 | 0.002232 | | |
| Rough-toothed dolphin | 0.006916 | 0.006546 | | |
| Common bottlenose dolphin | 0.081656 | 0.028930 | | |
| Pantropical spotted dolphin | 0.013061 | 0.010670 | | |
| Atlantic spotted dolphin | 0.021284 | 0.021119 | | |
| Atlantic white-sided dolphin[4] | 0.000006 | 0.000004 | | |
| White-beaked dolphin | 0.000000 | 0.000000 | | |
| Spinner dolphin | 0.026713 | 0.026492 | | |
| Striped dolphin | 0.001807 | 0.004373 | | |
| Clymene dolphin | 0.020654 | 0.021800 | | |
| Fraser's dolphin | 0.002539 | 0.002926 | | |
| Common dolphin | 0.001796 | 0.001206 | | |
| Short-finned pilot whale[5] | 0.023968 | 0.025140 | | |
| Killer whale | 0.000024 | 0.000024 | | |
| False killer whale | 0.003016 | 0.002983 | | |
| Pgymy killer whale | 0.001742 | 0.001782 | | |
| Melon-headed whale | 0.013398 | 0.013531 | | |
| **HF Cetaceans** | | | | |
| Kogia[6] | 0.004750 | 0.005055 | | |
| Pygmy sperm whale | | | | |
| Dwarf sperm whale | | | | |
| Harbor porpoise | 0.000001 | 0.000001 | | |
| **Sea Turtle** | | | | |
| Hawksbill Sea Turtle | | | | |
| Olive Ridley Sea Turtle | | | | |
| Loggerhead Sea Turtle | | | **0.001604** | 0.005200 |
| Green Sea Turtle | | | **0.000492** | 0.002600 |
| Leatherback Sea Turtle | | | | **0.000180** |

Note: Blank spaces mean no data were available.

[1] Highest densities occur during December-March. [2] Highest densities occur in August for intermediate water and January for deep water. December-March. [3] Highest densities occur during October-February. [4] Highest densities occur in February for intermediate water and March for deep water. [5] Densities for *Globicephala* spp. [6] Densities for *Kogia* spp.

The estimated numbers of individuals potentially exposed are based on the 160-dB re 1 µPa$_{rms}$ 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 13 shows the estimates of the number of marine mammals that potentially could be exposed to ≥160 dB re 1 µPa$_{rms}$ during the proposed seismic surveys if no animals moved away from the survey vessel (see Appendix B for more details), along with the *Requested Take Authorization*. Species for which densities were very low and take calculations resulted in <0.3 individuals (i.e., Atlantic white-sided dolphin, white-beaked dolphin, harbor porpoise) have been excluded from Table 13. It should be noted that the exposure estimates assume that the proposed surveys would be completed; in fact, the calculated takes for cetaceans, pinnipeds, and sea turtles ***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 µPa$_{rms}$ 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 2013). The context of an exposure of a marine mammal to sound can affect the animal's initial response to the sound (e.g., Ellison et al. 2012; NMFS 2013; Hastie et al. 2021; Hückstädt et al. 2020; Southall et al. 2021; Miller et al. 2022). Southall et al. (2021) provide a detailed framework for assessing marine mammal behavioral responses to anthropogenic noise and note that use of a single threshold can lead to large errors in prediction impacts due to variability in responses between and within species.

Estimates of the numbers of marine mammals and sea turtles that could be exposed to seismic sounds from the 36-airgun array with received levels equal to Level A thresholds for various hearing groups (see Table 2), if there were no mitigation measures (shut downs when PSOs observe animals approaching or inside the EZs), are also given in Table 13. 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. Level A takes are considered highly unlikely for most marine mammal species that could be encountered in the proposed survey areas.

#### 4.1.1.6 Conclusions for Marine Mammals and Sea Turtles

The proposed seismic surveys would involve towing an airgun array, which introduces 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, § 3.8.7, and § 3.9.7 of 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. Consistent with past similar proposed actions, NSF has followed the *Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing* for estimating Level A takes for the Proposed Action involving the high-energy surveys; however, following a different methodology than used in the PEIS.

TABLE 13. Estimates of the possible numbers of individual marine mammals and sea turtles that could be exposed to Level B and Level A thresholds for various hearing groups during the proposed low- and high-energy seismic surveys off Puerto Rico, Northwest Atlantic Ocean.

| Species | Stock Abundance North Atlantic[1] | Abundance AFTT Area[2] | Level B Takes | Level A Takes[4] (High-Energy) | Level B + Level A % of AFTT Area Abundance [5] | Requested Level A+B Take Authorization[6] |
|---|---|---|---|---|---|---|
| **LF Cetaceans** | | | | | | |
| Humpback whale | 1,396 | 4,990 | 262 | 12 | 5.5 | 274 |
| Minke whale | 21,968 | 13,784 | 58 | 3 | 0.4 | 61 |
| Bryde's whale | | 536 | 6 | 0 | 1.2 | 6 |
| Fin whale | 6,802 | 11,672 | 0.4 | 0 | 0.0 | 2[7] |
| Sei whale | 6,292 | 19,530 | 22 | 1 | 0.1 | 23 |
| Blue whale | 402 | 191 | 1 | 0 | 0.8 | 1 |
| **MF Cetaceans** | | | | | | |
| Sperm whale | 4,349 | 64,015 | 481 | 1 | 0.8 | 482 |
| Beaked whales | 5,744 | 65,069 | 539 | 1 | 0.8 | 540 |
| Cuvier's beaked whale [8] | 5,744 | | N.A. | N.A. | N.A. | 179 |
| Blainville's beaked whale [8] | 10,107 | | N.A. | N.A. | N.A. | 179 |
| Gervais' beaked whale [8] | 10,107 | | N.A. | N.A. | N.A. | 179 |
| True's beaked whale | 10,107 | | N.A. | N.A. | N.A. | 3[9] |
| Risso's dolphin | 35,215 | 78,205 | 164 | 0 | 0.2 | 164 |
| Rough-toothed dolphin | 136 | 32,848 | 476 | 1 | 1.5 | 477 |
| Common bottlenose dolphin | 62,851 | 418,151 | 2128 | 4 | 0.5 | 2,132 |
| Pantropical spotted dolphin | 6,593 | 321,740 | 778 | 1 | 0.2 | 779 |
| Atlantic spotted dolphin | 39,921 | 259,519 | 1537 | 3 | 0.6 | 1,540 |
| Spinner dolphin | 4,102 | 152,511 | 1928 | 4 | 1.3 | 1,932 |
| Striped dolphin | 67,036 | 412,729 | 317 | 1 | 0.1 | 318 |
| Clymene dolphin | 4,237 | 181,209 | 1586 | 3 | 0.9 | 1,589 |
| Fraser's dolphin | | 19,585 | 213 | 0 | 1.1 | 213 |
| Common dolphin | 172,974 | 473,260 | 88 | 0 | 0.0 | 88 |
| Short-finned pilot whale [10] | 28,924 | 264,907 | 1830 | 3 | 0.7 | 1,833 |
| Killer whale | | 972 | 2 | 0 | 0.2 | 2 |
| False killer whale | 1,791 | 12,682 | 218 | 0 | 1.7 | 218 |
| Pgymy killer whale | | 9,001 | 130 | 0 | 1.4 | 130 |
| Melon-headed whale | | 64,114 | 985 | 2 | 1.5 | 987 |
| **HF Cetaceans** | | | | | | |
| *Kogia* spp. | 7,750 | 26,043 | 354 | 14 | 1.4 | 368 |
| Dwarf sperm whale [11] | 7,750 | | 177 | 7 | N.A. | 184 |
| Pygmy sperm whale [11] | 7,750 | | 177 | 7 | N.A. | 184 |
| **Sea Turtle** | | | | | | |
| Kemp's Ridley Sea Turtle | | | | | | |
| Hawksbill Sea Turtle | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. |
| Olive Ridley Sea Turtle | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. |
| Loggerhead Sea Turtle | N.A. | N.A. | 31 | 0 | N.A. | 31 |
| Green Sea Turtle | N.A. | N.A. | 9 | 0 | N.A. | 10 |
| Leatherback Sea Turtle | N.A. | N.A. | 3 | 0 | N.A. | 3 |

Blank cells mean no data available. N.A. means not applicable. [1]For North Atlantic and Gulf of Mexico from Hayes et al. (2022) and NMFS (2022). [2]For North Atlantic and Gulf of Mexico from Roberts et al. (2023). [3]Level B takes, based on the 160-dB criterion for marine mammals, excluding exposures to sound levels equivalent to PTS thresholds. [4]Level A takes if there were no mitigation measures, for the high-energy survey only. [5]Requested take authorization expressed as % of abundance from the AFTT area including both the Gulf of Mexico and the Northwest Atlantic, from Roberts et al. (2023). [6]Requested take authorization is Level A plus Level B calculated takes, unless indicated otherwise. [7]Minimum group size (Jefferson et al. 2015). [8]Assigned 1/3 of the Level B takes for all beaked whale species combined (minus True's beaked whale) to each of Cuvier's, Blaineville's, and Gervais' beaked whales. [9]Rounded up mean group size from Maze-Foley and Mullin (2006). [10]Takes were calculated using *Globicephala* sp. densities. [11]Take for *Kogia* spp. was equally divided between *K. sima* and *K. breviceps*.

For recent NSF-funded high energy 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 (e.g., NMFS 2019a,b).

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 (see Table 13). We calculated the percentages of population sizes that may be taken by dividing the take estimates by the population sizes based on habitat-density modeling for the AFTT area (western North Atlantic and GoM) from Roberts et al. (2023). The proposed activities are likely to adversely affect ESA-listed species for which takes are being requested (Table 14). The relatively short-term exposures are unlikely to result in any long-term negative consequences for the individuals or their populations. Therefore, no significant impacts on marine mammals would be anticipated from the proposed activities.

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. The proposed activities are likely to adversely affect ESA-listed sea turtles species for which takes were calculated (leatherback, loggerhead, and green sea turtles), as well as for hawksbill and olive ridley sea turtles for which no densities were available (Table 15).

TABLE 14. ESA determination for sea turtle species expected to be encountered during the proposed surveys off Puerto Rico in the Northwest Atlantic Ocean, fall 2023.

| | ESA Determination | | |
|---|---|---|---|
| **Species** | **No Effect** | **May Affect – Not Likely to Adversely Affect** | **May Affect – Likely to Adversely Affect** |
| Leatherback Turtle | | | √ |
| Hawksbill Turtle | | | √ |
| Green Turtle (North Atlatnic DPS) | | | √ |
| Green Turtle (South Atlantic DPS) | | | √ |
| Loggerhead Turtle (Northwest Atlantic DPS) | | | √ |
| Olive Ridley Turtle | | | √ |
| Hawksbill 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, 2020; Carroll et al. 2017: Popper and Hawkins 2019; Wale et al. 2021; Popper et al. 2022), 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, 2019). It is important to note that while all invertebrates and fishes are likely sensitive to particle motion, no invertebrates and not all fishes (e.g., sharks) are sensitive to the sound pressure component. Rogers et al. (2021) found that sounds from a seismic survey measured above ambient conditions up to 10 km away for particle acceleration and up to 31 km for sound pressure.

Substrate vibrations caused by sounds may also affect the epibenthos, but sensitivities are largely unknown (Roberts and Elliott 2017). Nonetheless, several studies have found that substrate-borne vibration and sound elicit behavioral responses in crabs (e.g., Roberts et al. 2016) and mussels (Roberts et al. 2015). Solan et al. (2015) also reported behavioral effects on sediment-dwelling invertebrates during sound exposure. Activities directly contacting the seabed would be expected to have localized impacts on invertebrates and fishes that use the benthic habitat. Activities directly contacting the seabed would be expected to have localized impacts on invertebrates and fishes that use the benthic habitat. A risk assessment of the potential impacts of airgun surveys on marine invertebrates and fish in Western Australia concluded that the greater the intensity of sound and the shallower the water, the greater the risk to these animals (Webster et al. 2018). In water >250 m deep, the impact of seismic surveying on fish and marine invertebrates was assessed as acceptable, while in water <250 m deep, risk ranged from negligible to severe, depending on depth, resource-type, and sound intensity (Webster et al. 2018). Immobile organisms, such as molluscs, were deemed to be the invertebrates most at risk from seismic impacts.

#### 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 including stress, injuries, mortalities (Wale et al. 2013a,b; Aguilar de Soto 2016; Edmonds et al. 2016; Carroll et al. 2017; Weilgart 2017b; Elliott et al. 2019; Day et al. 2021), and stress (Celi et al. 2013; Vazzana et al. 2020). Jézéquel et al. (2021) recently reported that shipping noise can mask sounds produced by European lobster (*Homarus gammarus*), and that they may change sound production in response to noise. The available information suggests that invertebrates, particularly crustaceans, may be relatively resilient to airgun sounds (Day et al. 2016a,b).

Fields et al. (2019) conducted laboratory experiments to study effects of exposure to airgun sound on the mortality, predator escape response, and gene expression of the copepod *Calanus finmarchicus* and concluded that the airgun sound had limited effects on the mortality and escape responses of copepods exposed within 10 m of the airgun source but no measurable impact beyond that distance. McCauley et al. (2017) conducted a 2-day study to examine the potential effects of sound exposure of a 150 $in^3$ 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.

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 dB re 1 $\mu Pa^2 \cdot s$ SEL. Increases in alarm responses were seen at SELs >147–151 dB re 1 $\mu Pa^2 \cdot s$; 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 μPa and peak levels up to 175 dB re 1 μPa. 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 $\mu Pa^2$. 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 in$^3$ array made up of 16 airguns operating at 2000 psi with a maximum SEL of 146 dB re 1 μPa$^2 \cdot$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 rock 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 in$^3$, 150 in$^3$ (low pressure), and 150 in$^3$ (high pressure), each with maximum peak-to-peak source levels of 191–213 dB re 1 μPa; maximum cumulative SEL source levels were 189–199 dB re 1 μPa$^2 \cdot$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 either control or exposed lobsters (Day et al. 2016a,b). When Day et al. (2019, 2021) exposed noise naïve rock lobster to the equivalent of a full-scale commercial seismic survey passing within 100–500 m, adult and juvenile lobsters exhibited impaired righting and damage to the sensory hairs of the statocyst. Lobsters that were exposed at a more distant range showed recovery, whereas those exposed at closer range had persistent impairment (Day et al. 2019, 2021). Day et al. (2021) noted that there was indication for slowed growth and physiological stress and juvenile lobsters after exposure. Adult lobsters that were collected from areas with high anthropogenic noise were shown to have pre-existing damage to the statocysts which were not damaged further upon exposure to airgun sounds (Day et al. 2020). However, lobsters from noisy environments appeared to be better able to cope with the damage than noise naïve lobsters; they did not show any disruption to the righting reflex (Day et al. 2020).

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 haemolyph 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 (*Cancer magister*) larvae or snow crab (*Chionoecetes opilio*) 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 µPa$_{rms}$ 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 heptapancreas. 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 µPa$_{rms}$, 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.

Cote et al. (2020) conducted a study using the multi-year Before-After/Control-Impact (BACI) approach in the Carson and Lilly Canyons to evaluate the potential of industry-scale seismic exposure to modify movement behavior of free-ranging adult male snow crab. The crabs were exposed to a commercial seismic array, with a total volume of 4880 in$^3$, horizontal SPL$_{0\text{-}p}$ of 251 dB re 1 µPa, and SEL of 229 dB re 1 µPa$^2$·s (the same seismic source as used by Morris et al. 2018, noted below). Movements of snow crabs were tracked using a hyperbolic acoustic positioning array. In total, 201 and 115 snow crabs were tagged in Carson and Lilly canyons, respectively. Before, during, and after exposure periods to a single seismic surveying line of 5–8 hours in duration, were matched in time across control and test sites—each site monitored an area 4 km$^2$. There were no obvious effects of seismic exposure on the movement ecology of adult male snow crab; variation in snow crab movement was primarily attributable to individual variation and factors like handling, water temperature, and time of day. The authors concluded that seismic exposure did not have any important effects on snow crab movement direction, and any variance in the results were shown to be individual-specific. Snow crabs are known to display highly variable movement behavior and individual-specific tendencies can explain experimental variance (Cote et al. 2020). Snow crab have also been considered to be less vulnerable to physiological damages from noise due to their absence of gas filled organs such as swim bladders that are sensitive to seismic exposures (Cote et al. 2020). There was also no evidence of physical damage to internal organs based on histological examinations (Morris et al. 2021).

Hall et al. (2021) collected tissue samples to investigate the potential impact of seismic surveying on the transcriptome responses of snow crab hepatopancreas. The hepatopancreas is an organ that aids in the absorption and storage of nutrients and produces important digestive enzymes and is therefore assumed to be an indicator suitable for determining the effect of sound exposure effects on crab physiology and health. Snow crabs were subjected to 2-D seismic noise in 2016 for two hours and sampled before, 18 hours and three weeks after exposure. In 2017, 2-D seismic exposure was repeated, and samples were collected prior to seismic testing, and 1 day, 2 days, and 6 weeks after exposure. Additionally, in 2017 snow crabs were subjected to 3-D seismic noises for 2 months and were sampled 6 weeks after exposure. Hall et al. (2021) identified nine transcripts with significantly higher expression after 2-D seismic exposure, and 14 transcripts with significant differential expression between the test and control sites. These included transcripts with functional annotations related to oxidation-reduction, immunity, and metabolism. Significant changes for these transcripts were not observed during the 2017 field season. Thus, although transcript expression changes were detected in snow crab in response to seismic survey sound, the response was variable across years. Hall et al. (2021) concluded that although candidate molecular biomarkers identified in one field season (2016), they were not reliable indicators in the next year (2017), and further study is warranted.

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 $in^3$. 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 $_{0\text{-pk}}$ were 204 dB re 1 $\mu Pa^2 \cdot s$ 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

Popper et al. (2019a) and Popper and Hawkins (2021) recently reviewed the hearing ability of fishes, and 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), Weilgart (2017b), Hawkins and Popper (2018), Popper et al. (2019b), and Slabbekoorn et al. (2019); they include pathological, physiological, and behavioral effects. Radford et al. (2014), Putland et al. (2017), and de Jong et al. (2020) noted that masking of key environmental sounds or social signals could also be a potential negative effect from sound. Mauro et al. (2020) concluded that noise exposure may have significant effects on fish behavior which may subsequently affect fitness and survival).

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) and Hawkins et al. (2020) cautioned that particle motion as well as sound pressure should be considered when assessing the effects of underwater sound on fishes.

Bruce et al. (2018) studied the potential behavioral impacts of a seismic survey in the Gippsland Basin, Australia, on three shark species: tiger flathead (*Neoplatycephalus richardsoni*), gummy shark (*Mustelus antarcticus*), and swellshark (*Cephaloscylum 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 2530 $in^3$ array consisting of 16 airguns with a maximum SEL of 146 dB re 1 $\mu Pa^2 \cdot s$ 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.

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.

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 $\mu Pa^2 \cdot s$ SEL. Increases in alarm responses were seen in the fish at SELs >147–151 dB re 1 $\mu Pa^2 \cdot s$; 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 $\mu Pa^2 \cdot s$.

Davidsen et al. (2019) outfitted Atlantic cod and saithe with acoustic transmitters to monitor their behaviors (i.e., swimming speed, movement in water column) in response to exposure to seismic airgun sound. The study was conducted in Norway using a large sea cage with a 30 m diameter and 25 m depth. Both sound pressure and particle motion were measured within the sea cage. An airgun firing every 10 s was towed toward the sea cage from an initial distance of 6.7 km from the cage to a minimum distance of 100 m from the cage. The $SEL_{cum}$ ranged from 172–175 dB re 1 $\mu Pa^2 \cdot s$. Both the cod and saithe changed swimming depth and horizontal position more frequently during exposure to the sound. The saithe became more dispersed in response to elevated sound levels. Both species exhibited behavioral habituation to the repeated exposures to sound.

van der Knaap et al. (2021) investigated the effects of a seismic survey on the movement behavior of free-swimming Atlantic cod in the southern North Sea. A total of 51 Atlantic cod were caught and tagged with acoustic transmitters and released in the southern North Sea where they were exposed to a towed airgun array 2.5 km from the tagged location over 3.5 days. The airgun array consisted of 36 airguns with a total volume of 2950 $in^3$, which fired every 10 s during operation in continuous loops, with parallel tracks of 25 km. The cumulative sound exposure level ($SEL_{cum}$ re 1 $\mu Pa^2 s$) over the 3.5-day survey period at the receiver position was 186.3 dB in the 40–400 Hz band. During sound exposure, cod became less locally active (moving small distances, showing high body acceleration) and more inactive (moving small distances, showing low body acceleration) at dawn and dusk which interrupted their diurnal activity cycle. The authors concluded that seismic surveying has the potential to affect energy budgets for a commercial fish species, which may have population-level consequences.

Hubert et al. (2020) exposed Atlantic cod in an aquaculture net pen to playback of seismic airgun sounds to determine the effect on swimming patterns and behavioral states. The fish were exposed to sound recordings of a downscaled airgun with a volume of (10 $in^3$) and a pressure of 800 kPa. During the experimental trials, the fish were exposed to mean zero-to-peak sound pressure levels ($SPL_{0\text{-}p}$) of 174, 169, and 152 dB re 1 µPa (0-pk) (100–600 Hz bandpass filter) with the speaker at 2, 7.8, and 20 m from the net pen, respectively. They found that individual cod within the net pen did not immediately change their swimming patterns after sound exposure; however, several individuals did change the amount of time they spent in three different behavioral states (transit, locally active, inactive) during the 1 h exposure.

Kok et al. (2021) found that fish exposed to the seismic survey at a wind farm changed their school cohesion compared with before exposure; there were also fewer schools detected during exposure. Nonetheless, they noted that no firm conclusions could be drawn from the studies, as fish behaved similarly at a control site.

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 $\mu Pa^2 \cdot s$)

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.

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 µPa$^2$/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 µPa$_{\text{rms}}$. 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 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 $1\mu Pa_{0\text{-}p}$, 243 dB re $1\mu Pa_{p\text{-}p}$, and 218 dB re $1\mu Pa_{rms}$. Received $SPL_{max}$ ranged from 107–144 dB re 1 µPa, and received $SEL_{cum}$ ranged from 111–141 dB re $1\mu Pa^2$-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.

Bruce et al. (2018) 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 three years before the seismic survey to six months after completion of the survey in an area 13,000 $km^2$. Overall, there was little evidence of consistent adverse impacts of the seismic survey on catch rates. Six of the 15 species were found to have increased catch rates.

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 $\mu Pa^2 \cdot s$). Meekan et al. (2021) also reported that a commercial seismic source had no short- or long-term effects on the tropical demersal fish community on the Northwest Shelf of Western Australia, as no changes on species composition, abundance, size structure, behavior, or movement were reported. The source level of the airgun array was estimated as 228 dB SEL and 247 dB re 1 µPa m peak-to-peak pressure.

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 µPa. 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 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 $in^3$, horizontal $SPL_{0\text{-}p}$ of 251 dB re 1 µPa, and SEL of 229 dB re 1 $\mu Pa^2 \cdot s$. 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.  Similarly, Cote et al. (2020) noted that the effects of seismic exposure on the behavior of adult male snow crab, are at most subtle and are "not likely to be a prominent threat to the fishery."

In 2017 and 2018, Morris et al. (2020, 2021) conducted another BACI study to investigate the effect of industrial 3-D seismic exposure on the catch rate of snow crab on the slope of the Grand Banks, at Carson Canyon with a control site at Lilly Canyon.  The duration of potential seismic exposure by the 4130 $in^3$ airgun array was nine and five weeks in 2017 and 2018, respectively.  Catch rates were inconsistent during the surveys; the catch rate at the experimental site was reduced in 2017, and higher catch rates were seen in 2018 in response to long-duration exposure.  The study concluded the observed effects of seismic surveying on snow crab catch rates were driven by spatiotemporal variation external to seismic exposure. The authors acknowledged that there is a possibility that seismic surveying may affect catch rates, but that any effects remain unpredictable in magnitude and direction, and that effects occur at short temporal and localized spatial scales.

#### 4.1.2.4 Conclusions for Invertebrates, Fish, Fisheries, EFH, and HAPC

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 fisheries would not be significant.

Interactions between the proposed surveys and fishing operations in the study 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 survey areas.  Fishing activities could occur within the proposed survey areas; 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 surveys.

Given the proposed activities, impacts would not be anticipated to be significant or likely to adversely affect (including proposed candidate or ESA-listed) marine invertebrates, marine fish (Table 16), and their fisheries, including commercial, recreational, artisanal, and subsistence fisheries. Most of the proposed survey effort would occur beyond the 12 n.mi. limit in deep waters, and would not affect recreational or artisanal fisheries.  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.  Although the proposed activities may affect EFH, adverse effects on EFH are unexpected given the short-term nature of the seismic surveys and minimal bottom disturbance. There are no HAPCs designated within the survey area; however, there are several HAPCs near and adjacent to the survey area; impacts on HAPCs would not be anticipated or would be very limited.

TABLE 15. ESA determination for fish and invertebrate species expected to be encountered during the proposed surveys off Puerto Rico in the Northwest Atlantic Ocean, fall 2023.

| | ESA Determination | | |
|---|---|---|---|
| **Species** | **No Effect** | **May Affect – Not Likely to Adversely Affect** | **May Affect – Likely to Adversely Affect** |
| ***Marine fish*** | | | |
| Giant manta ray | | √ | |
| Smalltooth sawfish | | √ | |
| Nassau grouper | | √ | |
| Scalloped Hammerhead Shark (Central Atlantic DPS) | | √ | |
| Scalloped Hammerhead Shark (Southwest Atlantic DPS) | | √ | |
| Oceanic Whitetip Shark | | √ | |
| ***Marine Invertebrates*** | | | |
| Queen conch (*proposed candidate*) | | √ | |

### 4.1.3 Direct Effects on Seabirds and Their Significance

The underwater hearing of seabirds (including loons, scaups, gannets, and ducks) has been investigated by Crowell (2016), and the peak hearing sensitivity was found to be between 1500 and 3000 Hz. 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 µPa$_{rms}$ (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, avoidance measures and unlikelihood of encounter, no effects to ESA-listed seabirds would be anticipated from the proposed action (Table 17). 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.

TABLE 16. ESA determination for seabird species expected to be encountered during the proposed surveys off Puerto Rico in the Northwest Atlantic Ocean, fall 2023.

| | ESA Determination | | |
|---|---|---|---|
| **Species** | **No Effect** | **May Affect – Not Likely to Adversely Affect** | **May Affect – Likely to Adversely Affect** |
| Roseate tern | √ | | |

### 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, fish, or marine invertebrates 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. No significant indirect impacts on marine mammals, sea turtles, seabirds, or fish would be expected.

### 4.1.5 Direct Effects on Cultural Resources and Their Significance

Subsistence and artisanal fisheries occur in the coastal and nearshore waters of the proposed survey areas. As noted above in Section 4.1.2.4, impacts would not be anticipated to be significant or likely to adversely affect marine invertebrates, marine fish, and their fisheries, including artisanal or subsistence fisheries. Interactions between the proposed surveys and fishing operations in the study area are expected to be limited. Although fishing would not be precluded in the survey areas, a safe distance would need to be kept from R/V *Langseth* and the towed seismic equipment. Conflicts would be avoided through communication with subsistence and artisanal fishers during the surveys.

Additionally, there are numerous aircraft- and ship-wrecks in the study area. However, the proposed activities are of short duration (~36 days), and most of the wrecks (and SCUBA dive sites) are in shallower water <100 m deep. Conflicts with SCUBA divers would be avoided through direct communication with dive operators during the surveys. Furthermore, OBSs would be deployed to avoid shipwrecks and would only cause minimal seafloor disturbances. Therefore, no adverse impacts to cultural resources or SCUBA diving activities, are anticipated.

The temporary deployment of small land-based seismometers would occur on private land in previously disturbed areas; therefore, no effects would be expected from the proposed activities on historic and cultural resources.

### 4.1.6 Direct Effects on Terrestrial ESA-listed Species

Although eight ESA-listed species could potentially occur near the land seismometer sites, care would be taken to not disturb these species during deployment or recovery of the instruments. Encounters with listed species would be unlikely at these previously disturbed sites. Further, as the proposed activities would involve minor ground disturbance activities, direct interaction with the few endangered bird species would not be anticipated and any with the reptile and plants would be easily avoided. Based on the species rare occurrence, planned avoidance measures during deployment, and the fact that all work would occur on private land in previously disturbed areas, no effects would be expected from the proposed activities on endangered species (Table 18). In addition, there is no critical habitat located within the action area; therefore, there would be no effects from the proposed activities on critical habitat.

TABLE 17. Endangered terrestrial species that could occur near the land seismometer deployment sites.

| | ESA Determination | | |
|---|---|---|---|
| **Species** | **No Effect** | **May Affect – Not Likely to Adversely Affect** | **May Affect – Likely to Adversely Affect** |
| *Birds* | | | |
| Puerto Rican broad-winged hawk | √ | | |
| Puerto Rico nightjar | √ | | |
| Puerto Rican parrot | √ | | |
| Puerto Rican sharp-shinned hawk | √ | | |
| *Reptiles* | | | |
| Puerto Rican boa | √ | | |
| *Flowering Plants* | | | |
| Palo De Ramon | √ | | |
| Palo de Rosa | √ | | |
| West Indian walnut | √ | | |

## 4.1.7 Cumulative Effects

Cumulative effects refer to the impacts on the environment that result from a combination of past, existing, and reasonably foreseeable projects and human activities. Cumulative effects can result from multiple causes, multiple effects, effects of activities in more than one locale, and recurring events. Human activities, when conducted separately or in combination with other activities, could affect marine animals in the study area. However, understanding cumulative effects is complex because of the animals' extensive habitat ranges, and the difficulty in monitoring populations and determining the level of impacts that may result from certain activities.

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 areas. However, the combination of the proposed surveys with the existing operations in the region would be expected to produce only a negligible increase in overall disturbance effects on marine mammals.

### 4.1.7.1 Past and Future Research and Naval Activities

Several vessel-based and aerial surveys have been conducted in the Puerto Rico EEZ and the U.S. Virgin Islands for marine mammals and sea turtles, with the first surveys in 1984 (see DoN 2002). NOAA has been conducting its National Coral Reef Monitoring Program surveys since 2013. The Program includes biological, climate, and socioeconomic surveys of tropical coral reef habitats of ≤30 m depth in nine priority geographic areas, including Puerto Rico and the U.S. Virgin Islands (NOAA Coral Program 2021). Biological and climate data were collected in the Caribbean during 2013–2021. Since 2009, a real-time monitoring buoy has been operational offshore southwestern Puerto Rico (17.95°N, 67.05°W) within the La Parguera Natural Reserve. Onboard sensors provide climate and ecosystem monitoring (i.e., to detect ocean acidification) at this sensitive coral reef environment. Since 2016, scientists of the Conservación ConCiencia program have been working cooperatively with fishers and the Mote Marine Laboratory to conduct shark research in the Puerto Rico EEZ (Conservación ConCiencia 2020; Márquez 2021). The program seeks to build a baseline database of the shark species in the region and their distributions, including shallow-water, coastal, and deep-water marine habitats (Márquez 2021). The research occurs year-round in Puerto Rico and includes events such as video data collection for the Discovery Channel's "Shark Week", and monitoring and cleanup activities following the destruction wrought by Hurricane Maria during 2017 (Conservación ConCiencia 2020; Márquez 2021).

The position and strength of potential earthquakes and associated tsunamis in the Caribbean are estimated through USGS an ongoing project (USGS Coastal and Marine Hazards and Resources Program) that locates and plots geological faults in the area (USGS 2019, 2021). The program has a particular focus on the tectonically active Puerto Rico Trench region, and the use of light detection and ranging (lidar) technology to acquire land and seafloor elevation data to conduct vulnerability assessments of coastal areas in the British Virgin Islands (USGS 2019, 2021). The USGS's current strategic plan for the program spans from 2020–2030 (USGS 2019). 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 those described here, that are planned to occur in the proposed project area during fall 2023.

The U.S. Navy has also conducted some activities in the waters off Puerto Rico, in particular Vieques Island. The proposed study area is partially located in the Puerto Rico/St. Croix Operating Area (DoN 2002).

#### 4.1.7.2 Vessel Traffic

Sea ports located near the proposed transect lines include San Juan, Arecibo, Guánica, Guayanilla, and Ponce in Puerto Rico (SeaRates 2023). San Juan and Ponce are also international ports of entry (US Customs and Border Protection 2023). Vessel traffic in the proposed survey areas would mainly consist of cargo vessels and tankers, tugboats or other specialized crafts, passenger vessels, pleasure crafts, chartered diving vessels, and whale watching vessels. Based on data available through the U.S. Coast Guard (USCG) Automated Mutual-Assistance Vessel Rescue System (AMVER), the monthly density plot totals for the shipping lanes that occur in the survey areas included four or fewer vessels per month within 60' latitude by 60' longitude cells during September, October, and November 2022, with possibly up to 14 vessels per month off northwestern and southwestern Puerto Rico (USCG 2023). When live vessel traffic information for the area was accessed during November 2021, there were numerous cargo vessels, tankers, tugs, passenger vessels, and pleasure crafts identified within the proposed survey areas (MarineTraffic 2021). The total transit time by the survey vessel would be minimal relative to the number of other vessels operating in the proposed survey areas during fall 2023. Thus, the combination of the survey vessel's operations with the existing shipping operations is expected to produce only a negligible increase in overall ship disturbance effects on marine mammals.

#### 4.1.7.3 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*.—**Fisheries bycatch and vessel strikes are the primary threats to marine mammals in the WCR (Kiszka 2014; Luksenburg 2014). Bycatch of marine mammals has been documented in gillnet fisheries in Belize (manatees); Columbia and Mexico (manatees, mysticetes, and odontocetes); Venezuela (manatees and odontocetes); the Dominican Republic (dolphins); and Puerto Rico (odontocetes and sirenians) (Reeves et al. 2013; Kiszka 2014). Local ecological knowledge collected from commercial fishers off southeastern Puerto Rico indicated that manatees are most associated with bays and sea grass habitats in the region (García-Quijano 2007). This suggests that fisheries interactions with this vulnerable species are more likely to occur within these coastal environments, such as the incidental manatee captures reported by several interviewed artisanal fishers off northeastern Dominican Republic, including at least one bycatch occurrence in a beach/seine net (Kiszka 2014).

Although declining in frequency, directed hunting for cetaceans also occurs in the WCR, despite protections in place by numerous countries forbidding the practice (Kiszka 2014). In 2000, the SPAW Protocol entered into force as the WCR's sole legal agreement to further the conservation and protection of the marine environment (UNEP-CEP 2016). The Protocol prohibits the capture, take, or possession of any marine mammal species listed under its Annex II, except for traditional use for cultural or subsistence purposes. The Protocol further stipulates the creation of conservation, recovery, or management plans and procedures to address protected species.

***Sea turtles***.—Although prohibitions against the practice are in place in many countries within the WCR, sea turtles in the area are still hunted for the consumption of their meat (Kiszka 2014). Sea turtles are otherwise caught as bycatch in commercial longline, trawl, and gillnet fisheries in the region (Kiszka 2014). During 1990–2008, at least 5971, 1384, and 135 sea turtles were caught as bycatch in Caribbean gillnet, longline, and trawl fisheries, respectively (Wallace et al. 2010). On average, an estimated 374 sea turtles are caught per year in the artisanal longline fisheries of Barbados, with the majority of bycatch comprised of leatherback turtles (Blades et al. 2019). Interviewed artisanal fishers from northeastern Dominican Republic also reported incidental sea turtle catch using gillnets (41% of respondents), beach/purse seines (35%), and hook and lines (18%) (Kiszka 2014). Aucoin and León (2007) estimated that one hawksbill turtle per day is taken as bycatch in gillnets in artisanal fisheries in the Jaragua National Park region of the Caribbean UNESCO Biosphere Reserve off southwest Dominican Republic, with anecdotal evidence suggesting that trammel and lobster nets are responsible for an even higher rate of sea turtle bycatch in the region. In addition to direct mortality by drowning due to entanglement or being caught on hooks (e.g., Aucoin and León 2007), sea turtles may strand following an encounter with fishing gear. Aucoin and León (2007) observed one stranded, deceased juvenile hawksbill that had flipper damage consistent with injuries caused by monofilament netting.

Entanglement of sea turtles in seismic gear is also a concern; there have been anecdotal reports of turtles being trapped and killed between the gaps in tail-buoys and airgun arrays offshore of West Africa (Nelms et al. 2016). The probability of entanglements would be a function of turtle density in the proposed survey areas. Towing of hydrophone streamers or other equipment is not expected to significantly interfere with sea turtle movements, including migration, unless they were to become entrapped as indicated above.

***Seabirds***.**—**Entanglement in fishing gear and hooking can also lead to mortality of seabirds. However, there were no recorded incidences of seabird bycatch in fisheries in the proposed survey areas during 1990–2008 (Lewison et al. 2014). An estimated 230 seabirds are killed per year in pelagic longline fisheries for tunas, swordfishes, and sharks in the Northwest Atlantic, Gulf of Mexico, and Caribbean, combined (Anderson et al. 2011). Hand lines and trolling have also been noted to cause incidental seabird catches (Soanes et al. 2016). Overall, a data gap regarding seabird bycatch in fisheries has been identified for the Caribbean, although the risk of fisheries interaction is likely low in the proposed survey areas, as relatively few diving species inhabit the region (Žydelis et al. 2013; Pott and Wiedenfeld 2017).

#### 4.1.7.4 Whale Watching

Whale watching has been a growing tourism industry in the Caribbean since the 1990s (Gero and Whitehead 2016). In 1998, over 39,000 people participated in whale watching in the Caribbean and West Indies, generating ~$10 million USD in revenue (Hoyt and Hvenegaard 2002). An estimated $96,000 of this revenue resulted from expenditures in Puerto Rico (Hoyt 2001). For many Caribbean countries, the whale watching industry saw considerable expansion from the 1990s to the 2000s. Peak whale watching in the Caribbean occurs from December/January–March, when whales migrate to the region to mate and calve (Riddle 2018; Wong 2020). Northwestern Puerto Rico is also a popular whale watching location, along with several other locations in the WCR (Hoyt 2001; Riddle 2018). Species that are viewed mainly include humpback whales, sperm whales, pygmy sperm whales, false killer whales, and various dolphins (Hoyt 2001; Hoyt and Hvenegaard 2002; Riddle 2018; Wong 2020). Tourists in the region participate in whale watching from shore, vessel-based tours, and commercial "swim-with-whales" operations (Gero and Whitehead 2016; Wong 2020). In 2000, Caribbean whale watch tour operators formed the Caribbean Whale Watch Association (CaribWhale 2016). CaribWhale seeks to promote sustainable whale watching and support "research, conservation, education, and advocacy" in the Caribbean region (CaribWhale 2016). Most whale watching activities occur close to shore, whereas the majority of the survey effort would occur in offshore waters.

### 4.1.8 Unavoidable Impacts

Unavoidable impacts to the species of marine mammals and sea turtles occurring in the proposed survey areas 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 sea 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.

### 4.1.9 Coordination with Other Agencies and Processes

This Draft EA has been prepared by LGL on behalf of L-DEO and NSF pursuant to NEPA and Executive Order 12114. USGS is a Cooperating Agency on the Draft EA. Potential impacts to marine mammals, endangered species, and critical habitat have also been assessed in the document; therefore, it will be used to support the ESA Section 7 and EFH consultation processes with NMFS and other U.S. and international regulatory processes as appropriate. This document will also be used as supporting documentation for an IHA application submitted by L-DEO, on behalf of itself NSF, WHOI, USGS, UTIG, and UPRM, to NMFS, under the U.S. MMPA, for "taking by harassment" (disturbance) of small numbers of marine mammals, for the proposed seismic surveys. The vessel operator will also coordinate with the U.S. Navy regarding OBS deployments and will seek appropriate vessel clearances through the US Department of State for activities occurring within foreign EEZs.

## 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 species attributable to the proposed activity; however, valuable data about the marine environment would be lost. Research that would provide new constraints for examining earthquake and tsunami hazards associated with the Puerto Rico Trench region, and USGS research to understand Earth processes and the natural hazards they pose to Puerto Rico and the Virgin Islands in order to increase public safety and reduce risk and economic loss, would not be undertaken. 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*
Darren Island, M.Sc., Wenatchee, WA
Chelsea Bishop, M.Sc., St. John's, NL
Colin Jones, B.Sc., St. John's, NL
Bruce Mactavish, St. John's, NL
Sarah Penney-Belbin, M.Sc., St. John's, NL
Nathan Putman, Ph.D., Bryan, TX
Skylar Tupper, M.Sc., Bozeman, MT
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.

Acosta, A., N. Nino-Rodriquez, 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.** 26:199-216.

Aerts, L., M.R. Jenkerson, V.E. Nechayuk, G. Gailey, R. Racca, A.L. Blanchard, L.K. Schwarz, and H.R. Melton. 2022. Seismic surveys near gray whale feeding areas off Sakhalin Island, Russia: assessing impact and mitigation effectiveness. **Env. Monit. Assess.** 194 (Suppl. 1):746.

Aguilar A. and R. García-Vernet. 2018. Fin whale *Balaenoptera physalus*. p. 368-371 *In:* B. Würsig, J.G.M. Thewissen, and K.M. Kovacs (eds.), Encyclopedia of Marine Mammals, 3rd ed. Academic Press/Elsevier, San Diego, CA. 1157 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.

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.

Aguilar-Perera, A., M. Schärer, and M. Valdés-Pizzini. 2006. Marine protected areas in Puerto Rico: Historical and current perspectives. **Ocean Coast. Manage**. 49:961-975.

Aldana Aranda, D., H.A. Oxenford, C. Bissada, M.E. Diaz, T. Brule, G.A. Delgado, I. Martinez Morales, and L. Frenkiel. 2014. Reproductive patterns of queen conch, *Strombus gigas,* (Mollusca, Gastropoda), across the wider Caribbean region. **Bull. Mar Sci.** 90(3):813-831.

Amorocho, D.F. 2001. Status and distribution of the hawksbill turtle, *Eretmochelys imbricata*, in the Wider Caribbean Region. p. 41-45 *In:* K.L. Eckert and F.A.A. Grobois (eds.) Proceedings of the Regional Meeting: Marine Turtle Conservation in the Wider Caribbean Region: A Dialogue for Effective Regional Management, Santo Domingo, 16-18 November 1999, WIDECAST, IUCN-MTSG, WWF, and UNEP-CEP.

Anderson, O.R.J., C.J. Small, J.P. Croxall, E.K. Dunn, B.J. Sullivan, O. Yates, and A. Black. 2011. Global seabird bycatch in longline fisheries. **Endang. Species Res.** 14:91-106.

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.

Appeldoorn, R. and S. Meyers. 1993. Puerto Rico and Hispaniola. p. 99-158 *In:* Marine fishery resources of the Antilles. FAO Fisheries Technical Paper No. 326.

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.

Aucoin, S. and Y.M. León. 2007. Preliminary data on hawksbill turtle (*Eretmochelys imbricata*) bycatch in an artisanal gillnet used near Jaragua National Park, Dominican Republic. Proceedings of the 60th Gulf and Caribbean Fisheries Institute, 5-9 November 2007, Punta Canada, Dominican Republic. Accessed December 2021 at https://www.researchgate.net/profile/Yolanda-Leon-4/publication/265977127_Preliminary_Data_on_Hawksbill_Turtle_Eretmochelys_imbricata_Bycatch_in_an_Artisanal_Gillnet_Used_Near_Jaragua_National_Park_Dominican_Republic/links/553fe30d0cf2320416ece947/Preliminary-Data-on-Hawksbill-Turtle-Eretmochelys-imbricata-Bycatch-in-an-Artisanal-Gillnet-Used-Near-Jaragua-National-Park-Dominican-Republic.pdf.

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.

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. Int. Whal. Comm. Working Pap. SC/58/E35. 13 p.

Baird, R.W. 2018a. Cuvier’s beaked whale *Ziphius cavirostris*. p. 234-237 *In:* B. Würsig, J.G.M. Thewissen, and K.M. Kovacs (eds.), Encyclopedia of Marine Mammals, 3rd Edition. Academic Press/Elsevier, San Diego, CA. 1157 p.

Baird, R.W. 2018b. False killer whale *Pseudorca crassidens*. p. 347-349 *In:* B. Würsig, J.G.M. Thewissen, and K.M. Kovacs (eds.), Encyclopedia of Marine Mammals, 3rd Edition. Academic Press/Elsevier, San Diego, CA. 1157 p.

Baird, R.W. 2018c. Pygmy killer whale *Feresa attenuata*. p. 788-790 *In:* B. Würsig, J.G.M. Thewissen, and K.M. Kovacs (eds.), Encyclopedia of Marine Mammals, 3rd Edition. Academic Press/Elsevier, San Diego, CA. 1157 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 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.

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.

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.

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.

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 August 2021 at https://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

Bessudo, S., G.A. Soler, A.P. Klimley, J.T. Ketchum, A. Hearn, and R. Arauz. 2011. Residency of the scalloped hammerhead shark (*Sphyrna lewini*) at Malpelo Island and evidence of migration to other islands in the Eastern Tropical Pacific. **Environ. Biol. Fish** 91(2):165-176.

Betancourt, L., A. Herrera-Moreno, and K. Beddall. 2012. Spatial distribution of humpback whales (*Megaptera novaeangliae*) in Samaná Bay, Dominican Republic. IWC document SC/64/O12.

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. 2021. IUCN Red List for birds. Downloaded from http://www.birdlife.org on 29/03/2021.

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.** 114(2):1130-1134.

Bjorndal, K.A., A.B. Bolten, M. Chaloupka, V.S. Saba, C. Bellini, M.A. Marcovaldi, A.J. Santos, L.F.W. Bortolon, A.B. Meylan, P.A. Meylan, and J. Gray. 2017. Ecological regime shift drives declining growth rates of sea turtles throughout the West Atlantic. **Global Change Biol.** 23(11):4556-4568.

Bjorndal, K.A., M. Chaloupka, V.S. Saba, C.E. Diez, R.P. van Dam, B.H. Krueger, J.A. Horrocks, A.J.B. Santos, C. Bellini, M.A.G. Marcovaldi, M. Nava, S. Willis, B.J. Godley, S. Gore, L.A. Hawkes, A. McGowan, M.J. Witt, T.B. Stringell, A. Sanghera, P.B. Richardson, A.C. Broderick, Q. Phillips, M.C. Calosso, J.A.B. Claydon, J. Blumenthal, F. Moncada, G. Nodarse, Y. Medina, S.G. Dunbar, L.D. Wood, C.J. Lagueux, C.L. Campbell, A.B. Meylan, P.A. Meylan, V.R. Burns Perez, R.A. Coleman, S. Strindberg, V. Guzmán-H., K.M. Hart, M.S. Cherkiss, Z. Hillis-Starr, I.F. Lundgren, R.H. Boulon Jr., S. Connett, M.E. Outerbridge, and A.B. Bolten. 2016. Somatic growth dynamics of West Atlantic hawksbill sea turtles: a spatio-temporal perspective. **Ecosphere** 7(5):e01279.

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.

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.** 29(4):E342-E365.

Blades, D.C., J. Walcott, and J.A. Horrocks. 2019. Leatherback bycatch in an eastern Caribbean artisanal longline fishery. **Endang. Species Res.** 40:329-335.

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.

Blumenthal, J.M., F.A. Abreu-Grobois, T.J. Austin, A.C. Broderick, M.W. Bruford, M.S. Coyne, G. Ebanks-Petrie, A. Formia, P.A. Meylan, A.B. Meylan, and B.J. Godley. 2009. Turtle groups or turtle soup: dispersal patterns of hawksbill turtles in the Caribbean. **Mol. Ecol.** 18:4841-4853.

Bolaños-Jiménez, J., A.A. Mignucci-Giannoni, J. Blumenthal, A. Bogomolni, J.J. Casas, A. Henríquez, M. Iniguez Bessega, J. Khan, N. Landrau-Giovannetti, C. Rinaldi, and R. Rinaldi. 2014. Distribution, feeding habits and morphology of killer whales Orcinus orca in the Caribbean Sea. **Mamm. Rev.** 44(3-4):177-189.

Bovery, C.M. and J. Wyneken. 2015. Seasonal variation in sea turtle density and abundance in the southeast Florida current and surrounding waters. **PloS ONE** 10(12):e0145980.

Bowen, B.W., A.L. Bass, A. Garcia-Rodriguez, C.E. Diez, R. van Dam, A. Bolten, K.A. Bjorndal, M.M. Miyamoto, and R.J. Ferl. 1996. Origin of Hawksbill Turtles in a Caribbean Feeding Area as Indicated by Genetic Markers. **Ecol. Appl.** 6:566-572.

Branstetter, B.K. and J.M. Sills. 2022. Mechanisms of auditory masking in marine mammals. **Animal Cogn.** 25(5):1029-1047.

Branstetter, B.K., J.S. Trickey, 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.

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.

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.

Bruce, B., R. Bradford, S. Foster, K. Lee, M. Lansdell, S. Cooper, and R. Przeslawski. 2018. Quantifying fish behaviour and commercial catch rates in relation to a marine seismic survey. **Mar. Environ. Res.** 140:18-30.

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.

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.

Caldwell, D.K. and M.C. Caldwell. 1971. The pygmy killer whale, *Feresa attenuata*, in the western Atlantic, with a summary of world records. **J. Mammal**. 52(1):206-209.

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.

Carboneras, C., G.M. Kirwan, and F. Jutglar. 2020. Black-capped Petrel (*Pterodroma hasitata*). *In:* J. del Hoyo, A. Elliott, J. Sargatal, D.A. Christie, and E. de Juana (eds.) Handbook of the Birds of the World Alive. Lynx Edicions, Barcelona. Retrieved from https://www.hbw.com/node/52523 on 29 March 2021.

Cardona-Maldonado, M.A. and A.A. Mignucci-Giannoni. 1999. Pygmy and dwarf sperm whales in Puerto Rico and the Virgin Islands, with a review of Kogia in the Caribbean. **Caribb. J. Sci.** 35(1-2):29-37.

CaribWhale. 2016. CaribWhale Facebook profile page. Accessed December 2021 at https://www.facebook.com/Caribwhale/about/?ref=page_internal.

Carlson J., S. Gulak, C.A. Simpfendorfer, D. Grubbs, J. Romine, and G. Burgess. 2014. Movement patterns and habitat use of smalltooth sawfish, *Pristis pectinata*, determined using pop-up satellite archival tags. **Aquatic Conserv. Mar. Freshw. Ecos**. doi:10.1002/aqc.2382.

Carr, A., M.H. Carr, and A.B. Meylan. 1978. The ecology and migrations of sea turtles: the west Caribbean green turtle colony. **Bull. Am. Mus. Hist.** 162(1):1-46.

Carreras, C., B.J. Godley, Y.M. León, L.A. Hawkes, O. Revuelta, J.A. Raga, and J. Tomás. 2013. Contextualising the last survivors: population structure of marine turtles in the Dominican Republic. **PloS ONE** 8:e66037.

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.

CAR-SPAW-RAC. 2021. List of protected areas listed under SPAW Protocol (Cartagena Convention). Ministry of Ecological and Solidarity Transition. Accessed November 2021 at https://www.car-spaw-rac.org/?Marine-Protected-Areas.

Carwardine, M. 1995. Whales, dolphins and porpoises. Dorling Kindersley Publishing, Inc., New York. 256 p.

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). 2021a. Background on the EBSA process. Accessed November 2021 at https://www.cbd.int/ebsa/about.

CBD. 2021b. Ecologically or Biologically Significant Marine Areas. Accessed November 2021 at https://www.cbd.int/ebsa/ebsas.

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.

CFMC (Caribbean Fishery Management Council). 1998. Essential fish habitat (EFH) generic amendment to the Fishery Management Plans (FMPs) of the U.S. Caribbean including a Draft Environmental Assessment. Volume 1. San Juan: Caribbean Fishery Management Council.

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, and 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, I., T. Haug, and N. Øien. 1992. Seasonal distribution, exploitation and present abundance of stocks of large baleen whales (Mysticeti) and sperm whales (*Physeter macrocephalus*) in Norwegian and adjacent waters. ICES**. J. Mar. Sci.** 49:341-355.

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. 2018. Humpback whale Megaptera novaeangliae. p. 489-492 *In:* B. Würsig, J.G.M. Thewissen, and K.M. Kovacs (eds.), Encyclopedia of Marine Mammals, 3rd Edition. Academic Press/Elsevier, San Diego, CA. 1157 p.

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.

Conservación ConCiencia. 2020. Conservación ConCiencia. Accessed November 2021 at https://www.conservacionconciencia.org/what-we-do.

Costa, D.P. and T.M. Williams. 1999. Marine mammal energetics. p. 176-217 *In:* J.E. Reynolds III and S.A. Rommel (eds.) Biology of marine mammals. Smithsonian Institution Press, Washington. 578 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.

Cote, D., C.J. Morris, P.M. Regular, and M.G. Piersiak. 2020. Effects of 2D seismic on snow crab movement behaviour. **Fish. Res.** 230:1-10.

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.

Davidsen, J.G., H. Dong, M. Linné, M.H. Andersson, A. Piper, T.S. Prystay, E.B. Hvam, E.B. Thorstad, F. Whoriskey, S.J. Cooke, A.D. Sjursen, L. Rønning, T.C. Netland, and A.D. Hawkins. 2019. Effects of sound exposure from a seismic airgun on heart rate, acceleration and depth use in free-swimming Atlantic cod and saithe. **Conserv. Physiol.** 7(1):coz020.

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.

Davis, R.W., J.G. Ortega-Ortiz, C.A. Ribic, W.E. Evans, D.C. Biggs, P.H. Ressler, R.B. Cady, R.R Lebend, K.D. Mullin, and B. Würsig. 2002. Cetacean habitat in the northern oceanic Gulf of Mexico. **Deep-Sea Res.** I 49(1):21-142.

Day, R.D., Q.P. Fitzgibbon, R.D. McCauley, and J.M. Semmens. 2021. Examining the potential impacts of seismic surveys on octopus and larval stages of southern rock lobster - Part A: Southern rock lobster. FRDC project 2019-051.

Day, R.D., Q.P. Fitzgibbon, R.D. McCauley, K. Hartmann, and J.M. Semmens. 2020. Lobsters with pre-existing damage to their mechanosensory statocyst organs do not incur further damage from exposure to seismic air gun signals. **Environ. Poll.** 267:115478.

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.

Day, R.D., R.D. McCauley, Q.P. Fitzgibbon, K. Hartmann, and J.M. Semmens. 2019. Seismic air guns damage rock lobster mechanosensory organs and impair righting reflex. **Proc. Roy. Soc. B Biol. Sci**. 286(1907):20191424.

de Jong, K., T.N. Foreland, M.C.P. Amorim, G. Rieucau, H. Slabbekoorn, and L.D. Sivle. 2020. Predicting the effects of anthropogenic noise on fish reproduction. **Rev. Fish Biol. Fish.** 3:245-268.

Debrot, A.O. 1998. New cetacean records for Curaçao, Netherlands Antilles. **Caribb. J. Sci.** 34(1-2):168-169.

Debrot, A.O., N. Esteban, T. Bervoets, P.C. Hoetjes, and M. Scheidat. 2013. Marine Mammals of the Northeastern Caribbean Windward Dutch Islands: Saba, St. Eustatius, St. Maarten, and the Saba Bank. **Caribb. J. Sci.** 47(2–3):159-172.

Delarue, J., R. Dziak, D. Mellinger, J. Lawson, H. Moors-Murphy, Y. Simard, and K. Stafford. 2014. Western and central North Atlantic fin whale (*Balaenoptera physalus*) stock structure assessed using geographic song variations. **J. Acoust. Soc. Am.** 135(4):2240.

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.

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.

Di Iorio, L. and C.W. Clark. 2010. Exposure to seismic survey alters blue whale acoustic communication. **Biol. Lett.** 6(1):51-54.

Doksæter, L., E. Olsen, L. Nøttestad, and A. Fernö. 2008. Distribution and feeding ecology of dolphins along the Mid-Atlantic Ridge between Iceland and the Azores. **Deep Sea Res. II** 55(1-2):243-253.

Dive Advisor. 2021. Scuba diving in Puerto Rico. Accessed November 2021 at https://diveadvisor.com/puerto-rico.

Dive Buddy. 2021. Scuba Earth. Accessed November 2021 at https://www.divebuddy.com/scubaearth.

Dolar, M.L.L. 2018. Fraser's dolphin *Lagenodelphis hosei*. p. 392-395 In: B. Würsig, J.G.M. Thewissen, and K.M. Kovacs (eds.), Encyclopedia of Marine Mammals, 3rd Edition. Academic Press/Elsevier, San Diego, CA. 1157 p.

Dolman, S.J. and M. Jasny. 2015. Evolution of marine noise pollution management. **Aquat. Mammal**. 41(4):357-374.

DoN (Department of the Navy). 2002. Marine Resource Assessment for the Puerto Rico/St. Croix Operating Area, Final Report. Norfolk, VA.

DoN. 2017. Criteria and thresholds for U.S. Navy Acoustic and Explosive Effects Analysis (Phase III). Technical report prepared by the U.S. Navy.

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.

Donovan, G.P. 1991. A review of IWC stock boundaries. Rep. Int. Whal. Comm. Spec. Iss. 13:39-63.

Drew, C.A., L.B. Alexander-Vaughn, and J.A. Collazo. 2012. Science summary in support of Manatee Protection area (MPA) design in Puerto Rico. NC State University Technical Bull. 330, Raleigh, NC.

DRNA. 2007. Reserva natural Caño Tiburones. Estado Libre Asociado de Puerto Rico, Departamento de Recursos Naturales y Ambientales. 2 p. Accessed November 2021 at https://www.drna.pr.gov/wp-content/uploads/2015/04/Reserva-Natural-Ca%C3%B1o-Tiburones.pdf.

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. 2018. The communication space of humpback whale social sounds in vessel noise. Proceedings of Meetings on Acoustics 35(1):010001.

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. 2015. The effect of vessel noise on humpback whale, *Megaptera novaeangliae*, communication behaviour. **Animal Behav.** 111:13-21.

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.

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, 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.

Dunlop, R.A., M.J. Noad, R.D. McCauley, E. Kniest, R. Slade, D. Paton, and D.H. Cato. 2018. A behavioural dose-response model for migrating humpback whales and seismic air gun noise. **Mar. Poll. Bull.** 133:506-516.

Dunlop, R.A., R.D. McCauley, and M.J. Noad. 2020. Ships and air guns reduce social interactions in humpback whales at greater ranges than other behavioral impacts. **Mar. Poll. Bull.** 154:111072.

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., J. Braithwaite, L.O. Mortensen, and C.M. Harris. 2021. Assessing population-level effects of anthropogenic disturbance on a marine mammal population. **Front. Mar. Sci.** 8:624981.

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.

Eckert, K.L. and A.E. Eckert. 2019. An Atlas of Sea Turtle Nesting Habitat for the Wider Caribbean Region. Revised Edition. WIDECAST Technical Report. Godfrey, IL, WIDECAST.

Eckert, K.L., B.P. Wallace, J.G. Frazier, S.A. Eckert, and P.C.H. Pritchard. 2012. Synopsis of the biological data on the leatherback sea turtle (*Dermochelys coriacea*). U.S. Department of Interior, Fish and Wildlife Service, Biol. Tech. Publ. BTP-R4015-2012, Washington, DC.

Eckert, K.L., S.A. Eckert, T.W. Adams, and A.D. Tucker. 1989. Inter-nesting migrations by leatherback sea turtles (*Dermochelys coriacea*) in the West Indies. **Herpetol.** 45:190-194.

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). **Mamm. Rev.** 45(4):197-214.

Elliott, B.W., A.J. Read, B.J. Godley, S.E. Nelms, and D.P. Nowacek. 2019. Critical information gaps remain in understanding impacts of industrial seismic surveys on marine invertebrates. **Endang. Species Res.** 39:247-254.

Ellison, W.T., B.L. Southall, A.S. Frankel, K. Vigness-Raposa, and C.W. Clark. 2018. An acoustic scene perspective on spatial, temporal, and spectral aspects of marine mammal behavioral responses to noise. **Aquat. Mamm.** 44(3):239-243.

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.

Erbe, C., S.A. Marley, R.P. Schoeman, J.N. Smith, L.E. Trigg, and C.B. Embling. 2019. The effects of ship noise on marine mammals—a review. **Front. Mar. Sci.** 6:606.

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 ed. Academic Press, San Diego, CA. 1316 p.

Evans, P.G.H. 1987. The natural history of whales and dolphins. Christopher Helm, Bromley, Kent. 343 p.

Evans, P.G.H. 1992. Status review of cetaceans in British and Irish waters. U.K. Mammal Society Cetacean Group Report, University of Oxford. 100 p.

FAO (Food and Agriculture Organization of the United Nations). 1993. Marine fishery resources of the Antilles: Lesser Antilles, Puerto Rico and Hispaniola, Jamaica, Cuba. FAO Fisheries Technical Paper Number 326 1.

Farmer, N.A., K. Baker, D.G. Zeddies, S.L. Denes, D.P. Noren, L.P. Garrison, A. Machernis. E.M. Fougères, and M. Zykov. 2018. Population consequences of disturbance by offshore oil and gas activity for endangered sperm whales (*Physeter macrocephalus*). **Biol. Conserv.** 227:189-204.

Fay, R.R. and A.N. Popper. 2012. Fish hearing: new perspectives from two senior bioacousticians. **Brain Behav. Evol.** 79(4):215-217.

Fernandez-Betelu, O., I.M. Graham, K.L. Brookes, B.J. Cheney, T.R. Barton, and P.M. Thompson. 2021. Far-field effects of impulsive noise on coastal bottlenose dolphins. **Frontiers Mar. Sci.** 8:664230.

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.

Fertl, D., T.A. Jefferson, I.B. Moreno, A.N. Zerbini, and K.D. Mullin. 2003. Distribution of the Clymene dolphin *Stenella clymene*. **Mamm. Rev**. 33(3):253-271.

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.

Fields, D.M., N.O. Handegard, J. Dalen, C. Eichner, K. Malde, Ø. Karlsen, A.B. Skiftesvik, C.M.F. Durif, and H.I. Browman. 2019. Airgun blasts used in marine seismic surveys have limited effects on mortality, and no sublethal effects on behaviour of gene expression, in the copepod *Calanus finmarchicus*. ICES **J. Mar. Sci.** 76(7):2033-2044.

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. 2020. Conditional attenuation of dolphin monaural and binaural auditory evoked potentials after preferential stimulation of one ear. **J. Acoust. Soc. Am.** 147(4):2302-2313.

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, 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.

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 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., 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.

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 edsardsii*. **Mar. Poll. Bull.** 125(1-2):146-156.

Florida Museum. 2021. Scalloped hammerhead *Sphyrna lewini*. Accessed August 2021 at https://www.floridamuseum.ufl.edu/discover-fish/species-profiles/sphyrna-lewini/

Foley, A.M., K.E. Singel, P.H. Dutton, T.M. Summers, A.E. Redlow, and J. Lessman. 2007. Characteristics of a green turtle (*Chelonia mydas*) assemblage in northwestern Florida determined during a hypothermic stunning event. **Gulf Mex. Sci**. 25(2):4.

Ford, J.K.B. 2018. Killer whale *Orcinus orca*. p. 531-537 *In:* B. Würsig, J.G.M. Thewissen, and K.M. Kovacs (eds.) Encyclopedia of Marine Mammals, 3rd ed. Academic Press/Elsevier, San Diego, CA. 1157 p.

Fornet, M.E.H., L.P. Matthews, C.M. Gabriele, S. Haver, D.K. Mellinger, and H. Klinck. 2018. Humpback whales *Megaptera novaeangliae* alter calling behavior in response to natural sounds and vessel noise. **Mar. Ecol. Prog. Ser.** 607:251-268.

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., 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.

Frankel, A.S. and P.J. Stein. 2020. Gray whales hear and respond to signals from a 21–25 kHz active sonar. **Mar. Mamm. Sci.** 26(4):1111-1125.

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, 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.

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., M. Zykov, O. Sychenko, A. Rutenko, A.L. Blanchard, L Aerts, and R.H. Melton. 2022a. Gray whale density during seismic surveys near their Sakhalin feeding ground. **Env. Monit. Assess.** 194 (Suppl. 1):739.

Gailey, G., M. Zykov, O. Sychenko, A. Rutenko, A.L. Blanchard, L Aerts, and R.H. Melton. 2022b. Western gray whale behavioral response to seismic surveys during their foraging season. **Env. Monit. Assess.** 194 (Suppl. 1):740.

Gallagher, C.A., V. Grimm, L.A. Kyhn, C.C. Kinze, and J. Nabe-Nielsen. 2021. Movement and seasonal energetics mediate vulnerability to disturbance in marine mammal populations. **Am. Nat.** 197(3):296-311.

Gambell, R. 1985. 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.

Gannier, A. and J. Epinat. 2008. Cuvier's beaked whale distribution in the Mediterranean Sea: results from small boat surveys 1996–2007. **J. Mar. Biol. Assoc. U.K.** 88(6):1245-1251.

García, J.R., C. Schmitt, C. Heberer, and A. Winter. 1998. La Parguera, Puerto Rico, USA. p. 195-212 *In*: B. Kjerfve (ed.) CARICOMP Caribbean coral reef, seagrass and mangrove sites, UNESCO, Paris, France.

García, J.R., J. Morelock, R. Castro, C. Goenaga, and E. Hernández-Delgado. 2003. Puertorican reefs: research synthesis, preset threats and management perspectives. p. 111-130 *In* J.L. Cortés (ed.) Latin American Coral Reefs. Amsterdam: Elsevier. Accessed November 2021 at https://www.researchgate.net/publication/237269214_PUERTORICAN_REEFS_research_synthesis_present_threats_and_management_perspectives.

García-Quijano, C.G. 2007. Fishers' knowledge of marine species assemblages: Bridging between scientific and Local Ecological Knowledge in southeastern Puerto Rico. **Am. Anthro.** 109(3): 529-536.

Garrigue, C., A. Aguayo, V.L.U. Amante-Helweg, C.S. Baker, S. Caballero, P. Clapham, R. Constantine, J. Denkinger, M. Donoghue, L. Flórez-González, J. Greaves, N. Hauser, C. Olavarría, C. Pairoa, H. Peckham, and M. Poole. 2002. Movements of humpback whales in Oceania, South Pacific. **J. Cetac. Res. Manage.** 4(3):255-260.

Garrigue, C., P.J. Clapham, Y. Geyer, A.S. Kennedy, and A.N. Zerbini. 2015. Satellite tracking reveals novel migratory patterns and the importance of seamounts for endangered South Pacific humpback whales. **R. Soc. Open Sci.** 2:150489.

Gavilán, F.M. 2001. Status and distribution of the loggerhead turtle (*Caretta caretta*), in the wider Caribbean region. p. 36-40 In: Marine turtle conservation in the wider Caribbean region: a dialogue for effective regional management, St. Croix, US Virgin Islands.

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.

Gero, S. and H. Whitehead. 2016. Critical decline of the eastern Caribbean sperm whale population. **PloS ONE:** e0162019.

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.

Gleason, C.M. and E.C.M. Parsons. 2018. Research Note – To educate or not to educate: How the lack of education programs on whale-watching vessels can impact whale conservation and tourism in the Dominican Republic. **Tourism in Marine Environments** 13(2-3): 155-164.

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.

González-García, M. del Pilar., N.V. Schizas, M.V. Concepción-Torres, and C.E. Diez. 2021. *Lepidochelys olivacea* in Puerto Rico: Occurrence and Confirmed Nesting. Mar. Turtle Newsl. 162:13-17.

Gordon, A.L. 1967. Circulation of the Caribbean Sea. **J. Geophys. Res**. 72:6207–6223.

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.

Gospić, N.R. and M. Picciulin. 2016. Changes in whistle structure of resident bottlenose dolphins in relation to underwater noise and boat traffic. **Mar. Poll. Bull.** 105:193-198.

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.

Gregr, 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.

Griffin, L.P., J.T. Finn, C. Diez, and A.J. Danylchuk. 2019. Movements, connectivity, and space use of immature green turtles within coastal habitats of the Culebra Archipelago, Puerto Rico: implications for conservation. **Endang. Species Res.** 40:75-90.

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, A. and M. Day. 2014. Ecotourism in the State Forest Karst of Puerto Rico. **J. Cave Karst Stud**. 76(1): 30-41.

Hall, J.R., S.J. Lehnert, E. Gonzalez, S. Kumar, J.M. Hanlon, C.J. Morris, and M.L. Rise. 2021. Snow crab (*Chionoecetes opilio*) hepatopancreas transciptome: Identification and testing of candidate molecular biomarkers of seismic survey impact. **Fish. Res.** 234: 105794.

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 U.S. Atlantic Exclusive Economic Zone from 1992 vessel surveys. Southeast Fisheries Science Center, Miami Laboratory. Contribution No. MIA-93/94-58.

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 Srait. Tasmanian Aquaculture and Fisheries Institute, University of Tasmania.

Harris, C.M., L. Thomas, E.A. Falcone, J. Hildebrand, D. Houser, P.H. Kvadsheim, 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**. 55(1):396-404.

Hartman, K.L. 2018. Risso's dolphin *Grampus griseus*. p. 824-827 *In:* B. Würsig, J.G.M. Thewissen, and K.M. Kovacs (eds.), Encyclopedia of Marine Mammals, 3rd Edition. Academic Press/Elsevier, San Diego, CA. 1157 p.

Harwood, J. and B. Wilson. 2001. The implications of developments on the Atlantic Frontier for marine mammals. **Cont. Shelf Res.** 21(8-10):1073-1093.

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., N.D. Merchant, T. Götz, D.J. Russell, P. Thompson, and V.M. Janik. 2019. Effects of impulsive noise on marine mammals: investigating range-dependent risk. **Ecol. Appl.** 15:e01906.

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.

Hastie, G.D., P. Lepper, J.C. McKnight, R. Milne, D.J. Russell, and D. Thompson. 2021. Acoustic risk balancing by marine mammals: anthropogenic noise can influence the foraging decisions by seals. **J. Appl. Ecol.** 58(9):1854-1863.

Hasting, M. 2003. A conservation success: leatherback turtles in the British Virgin Islands. Mar. Turtle Newsl. 99:5-7.

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.

Hawkes, L.A., J. Tomás, O. Revuelta, Y.M. León, J.M. Blumenthal, A.C. Broderick, M. Fish, J.A. Raga, M.J. Witt, and B.J. Godley. 2012. Migratory patterns in hawksbill turtles described by satellite tracking. **Mar. Ecol. Prog. Ser.** 461:223-232.

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. and A.N. Popper. 2018. Effects of man-made sound on fishes. p.145-177 *In:* Slabbekoorn, H., R.J. Dooling,. A.N. Popper and R.R. Fay (eds.) Effects of Anthropogenic Noise on Animals. Springer International, Cham.

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. Fish.** 25(1):39-64.

Hawkins, A.D., C. Johnson, and A.N. Popper. 2020. How to set sound exposure criteria for fishes. **J. Acoust. Soc. Am.** 147(3):1762-1777.

Hayes, S.A., E. Josephson, K. Maze-Foley, and P.E. Rosel (eds). 2020. U.S. Atlantic and Gulf of Mexico Marine mammal stock assessments. NOAA Tech. Memo NMFS-NE-264.

Hayes, S.A., E. Josephson, K. Maze-Foley, P.E. Rosel, and J. Wallace (eds). 2022. U.S. Atlantic and Gulf of Mexico Marine mammal stock assessments 2021. NOAA Tech. Memo NMFS-NE-288.

Heenehan, H., J.E. Stanistreet, P.J. Corkeron, L. Bouveret, J. Chalifour, G.E. Davis, A. Henriquez, J.J. Kiszka, L. Kline, C. Reed, and O. Shamir-Reynoso. 2019. Caribbean Sea soundscapes: Monitoring humpback whales, biological sounds, geological events, and anthropogenic impacts of vessel noise. **Front. Mar. Sci.** 6:347.

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.

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., S.B. Blackwell, O.M. Tervo, A.L. Samson, E. Garde, R.G. Hansen, M.C. Ngô, A.S. Conrad, P. Trinhammer, H.C. Schmidt, M.-H.S. Sinding, T.M. Williams, and S. Ditlevsen. 2021. Behavioral response study on seismic airgun and vessel exposures in narwhals. **Front. Mar. Sci.** 8:658173.

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.

Hermannsen, 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.

Hermannsen, 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.

Hernández, N.A., C.J. Santos Flores, D. Pérez López, and M. Alfaro Lozano. 2021. Aquatic invertebrate communities in areas covered and devoid of floating fern *Salvinia* within the mangrove forest in the Boqurón Wildlife Refuge, Cabo Rojo, Puerto Rico. **Caribb. J. Sci.** 51:146-165.

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.

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.

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.

Horwood, J. 1987. The sei whale: population biology, ecology, and management. Croom Helm, Beckenham, Kent, UK. 375 p.

Horwood, J. 2018. Sei whale *Balaenoptera borealis*. p. 845-848 *In:* B. Würsig, J.G.M. Thewissen, and K.M. Kovacs (eds.), Encyclopedia of Marine Mammals, 3rd Edition. Academic Press/Elsevier, San Diego, CA. 1157 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.

Houser, D.S. 2021. When is temporary threshold shift injurious to marine mammals? **J. Mar. Sci. Eng.** 9(7):757.

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.** 41(3):1371-1413.

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.

Hoyt, E. 2001. Whale watching 2001: Worldwide tourism numbers, expenditures, and expanding socioeconomic benefits. International Fund for Animal Welfare, Yarmouth Port, MA, USA. 158 p. Accessed December 2021 at https://www.researchgate.net/profile/Erich-Hoyt/publication/272486618_Whale_Watching_2001_Worldwide_Tourism_Numbers_Expenditures_and_Expanding_Socioeconomic_Benefits/links/54e5d1230cf2bff5a4f1c6ec/Whale-Watching-2001-Worldwide-Tourism-Numbers-Expenditures-and-Expanding-Socioeconomic-Benefits.pdf.

Hoyt, E. and G.T. Hvenegaard. 2002. A review of whale-watching and whaling with applications for the Caribbean. **Coast. Manage.** 30:381-399.

Hubert, J., J.A. Campbell, and H. Slabbekorn. 2020. Effect of seismic airgun playbacks on swimming patterns and behavioural states of Atlantic cod in a net pen. **Mar. Poll. Bull**. 160:111680.

Hunter, M.E., A.A. Mignucci-Giannoni, K.P. Tucker, T.L. King, R.K. Bonde, B.A. Gray, and P.M. McGuire. 2012. Puerto Rico and Florida manatees represent genetically distinct groups. **Conserv. Genetics** 13(6):1623-1635.

Hückstädt, L.A., L.K. Schwarz, A.S. Friedlaender, B.R. Mate, A.N. Zerbini, A. Kennedy, J. Robbins, N.J. Gales, and D.P. Costa. 2020. A dynamic approach to estimate the probability of exposure of marine predators to oil exploration seismic surveys over continental shelf waters. **End. Spec. Res. 42**:185-199.

IAC (Inter-American Convention for the Protection and Conservation of Sea Turtles). 2015. Obligations of the parties. Accessed in December 2021. http://www.iacseaturtle.org/obligaciones-eng.htm

Isojunno, S., C. Curé, P.H. Kvadsheim, F.P.A. Lam, P.L. Tyack, P.J. Wensveen, and P.J.O.M. Miller, P.J.O.M. 2016. Sperm whales reduce foraging effort during exposure to 1–2 kHz sonar and killer whale sounds. **Ecol. Appl.** 26(1):77-93.

IUCN (International Union for Conservation of Nature). 2021. The IUCN Red List of Threatened Species. Version 2021-1. Accessed August 2021 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.

Jackson, J.A., D.J. Steel, P. Beerli, B.C. Congdon, C. Olavarría, M.S. Leslie, C. Pomilla, H. Rosenbaum, and C.S. Baker. 2014. Global diversity and oceanic divergence of humpback whales (*Megaptera novaeangliae*). **Proc. R. Soc.** B 281:20133222.

Jaquet, N. and D. Gendron. 2002. Distribution and relative abundance of sperm whales in relation to key environmental features, squid landings and the distribution of other cetacean species in the Gulf of California, Mexico. **Mar. Biol.** 141(3):591-601.

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. and N.B. Barros. 1997. *Peponocephala electra*. **Mamm. Spe**. 553:1-6.

Jefferson, T.A. and S.K. Lynn. 1994. Marine mammal sightings in the Caribbean Sea and Gulf of Mexico, summer 1991. **Caribb. J. Sci.** 30(1-2):83-89.

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.

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, U.K. 608 p.

Jefferson, T.A., D. Fertl, J. Bolanos-Jimenez and A.N. Zerbini. 2009. Distribution of common dolphins (*Delphinus* spp.) in the western North Atlantic: A critical re-examination. **Mar. Biol.** 156:1109-1124.

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.

Jézéquel, Y., J. Bonnel, and L. Chauvaud. 2021. Potential for acoustic masking due to shipping noise in the European lobster (*Homarus gammarus*). **Mar. Poll. Bull.** 173:112934.

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, 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.** 54(6):1930-1940.

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., 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.

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.

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, 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.

Kastelein, R.A., L. Helder-Hoek, and J.M. Terhune. 2018. Hearing thresholds, for underwater sounds, of harbor seals (*Phoca vitulina*) at the water surface. **J. Acoust. Soc. Am.** 143:2554-2563.

Kastelein, R.A., L. Helder-Hoek, and R. Gransier. 2019a. Frequency of greatest temporary hearing threshold shift in harbor seals (*Phoca vitulina*) depends on fatiguing sound level. **J. Acoust. Soc. Am.** 145(3):1353-1362.

Kastelein, R.A., L. Helder-Hoek, R. van Kester, R. Huisman, and R. Gransier. 2019b. Temporary threshold shift in harbor porpoises (*Phocoena phocoena*) due to one-sixth octave noise band at 16 kHz. **Aquatic Mamm.** 45(3):280-292.

Kastelein, R.A., L. Helder-Hoek, R. van Kester, R. Huisman, and R. Gransier. 2019c. Temporary threshold shift in harbor porpoises (*Phocoena phocoena*) due to one-sixth octave noise band at 16 kHz. **Aquatic Mamm.** 45(3):280-292.

Kastelein, R.A., L. Helder-Hoek, S. Cornelisse, L.A.E. Huijser, and Gransier. 2019d. Temporary threshold shift in harbor porpoises (*Phocoena phocoena*) due to one-sixth octave noise band at 32 kHz. **Aquatic Mamm.** 45(5):549-562.

Kastelein, R.A., L. Helder-Hoek, S.A. Cornelisse, L.A.E. Huijser, and J.M. Terhune. 2020a. Temporary hearing threshold shift in harbor seals (*Phoca vitulina*) due to a one-sixth-octave noise band centered at 32 kHz. **J. Acoust. Soc. Am.** 147(3):1885-1896.

Kastelein, R.A., C. Parlog., L. Helder-Hoek, S.A. Cornelisse, L.A.E. Huijser, and J.M. Terhune. 2020b. Temporary hearing threshold shift in harbor seals (*Phoca vitulina*) due to a one-sixth-octave noise band centered at 40 kHz. **J. Acoust. Soc. Am.** 147(3):1966-1976.

Kastelein, R.A., L. Helder-Hoek, S.A. Cornelisse, L.N. Defillet, L.A.E. Huijser, and J.M. Terhune. 2020c. Temporary hearing threshold shift in harbor seals (*Phoca vitulina*) due to a one-sixth-octave noise bands centered at 0.5, 1, and 2 kHz. **J. Acoust. Soc. Am.** 148(6):3873-3885.

Kastelein, R.A., L. Helder-Hoek, S.A. Cornelisse, L.N. Defillet, L.A.E. Huijser, and J.M. Terhune. 2020d. Temporary hearing threshold shift in harbor porpoises (*Phocoena phocoena*) due to one-sixth-octave noise bands centered at 63 kHz. **Aquatic Mamm.** 46(2):167-182.

Kastelein, R.A., L. Helder-Hoek, S.A. Cornelisse, L.A.E. Huijser, and J.M. Terhune. 2020e. Temporary hearing threshold shift at ecologically relevant frequencies in a harbor porpoises (*Phocoena phocoena*) due to exposure to a noise band centered at 88.4 kHz. **Aquatic Mamm.** 46(5):444-453.

Kastelein, R.A., L. Helder-Hoek, S.A. Cornelisse, L.N. Defillet, and L.A. Huijser. 2020f. Temporary hearing threshold shift in a second harbor porpoise (*Phocoena phocoena*) after exposure to a one-sixth-octave noise band at 1.5 kHz and 6.5 kHz continuous wave. **Aquatic Mamm.** 46(5):431-443.

Kastelein, R.A., L. Helder-Hoek, S.A. Cornelisse, A.M. von Benda-Beckmann, F.P.A. Lam, C.A.F. de Jong, and D.R. Ketten. 2020g. Lack of reproducibility of temporary hearing threshold shifts in a harbor porpoise after exposure to repeated airgun sounds. **J. Acoust. Soc. Am.** 148:556-565.

Kastelein, R.A., L. Helder-Hoek, L.N. Defillet, L.A. Huijser, J.M. Terhune, and R. Gransier. 2021a. Temporary hearing threshold shift in a harbor porpoise (*Phocoena phocoena*) due to exposure to a continuous one-sixth-octave noise band centered at 0.5 kHz. **Aquatic Mamm.** 47(2):135-145.

Kastelein, R.A., L. Helder-Hoek, L.N. Defillet, L.A. Huijser, J.M. Terhune, and R. Gransier. 2021b. Temporary hearing threshold shift in California sea lions (*Zalophus californianus*) due to one-sixth-octave noise bands centered at 2 and 4 kHz: effect of duty cycle and testing the equal-energy hypothesis. **Aquatic Mamm.** 47(4):394-418.

Kastelein, R.A., L. Helder-Hoek, L.N. Defillet, L.A. Huijser, J.M. Terhune, and R. Gransier. 2022. Temporary hearing threshold shift in California sea lions (*Zalophus californianus*) due to one-sixth-octave noise bands centered at 8 and 16 kHz: effect of duty cycle and testing the equal-energy hypothesis. **Aquatic Mamm.** 48(1):36-58.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.

Kato, H. and W.F. Perrin. 2018. Bryde's whale *Balaenoptera edeni*. p. 143-145 *In:* B. Würsig, J.G.M. Thewissen, and K.M. Kovacs (eds.) Encyclopedia of Marine Mammals, 3rd Edition. Academic Press/Elsevier, San Diego, CA. 1157 p.

Katona, S.K. and J.A. Beard. 1990. Population size, migrations and feeding aggregations of the humpback whale (*Megaptera novaeangliae*) in the western North Atlantic Ocean. Rep. Int. Whal. Comm. (Spec. Iss. 12): 295-306.

Kavanagh, A.S., M. Nykänen, W. Hunt, N. Richardson, and M.J. Jessopp. 2019. Seismic surveys reduce cetacean sightings across a large marine ecosystem. **Sci. Rep.** 9:19164.

Kennedy, A.S., A.N. Zerbini, O.V. Vásquez, N. Gandilhon, P.J. Clapham, and O. Adam. 2014. Local and migratory movements of humpback whales (*Megaptera novaeangliae*) satellite-tracked in the North Atlantic Ocean. **Can. J. Zool.** 92:8-17.

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.

Kiszka, J. 2014. Bycatch assessment of the West Indian manatee (*Trichechus manatus*) and other megafauna in artisanal fisheries in the Caribbean. Report by Florida International University, Department of Biological Sciences, for SPAW-RAC. 41 p. Accessed November 2021 at http://www.car-spaw-rac.org/IMG/pdf/manateebycatch_finalversion.pdf.

Klatsky, L.J. 2004. Movement and dive behavior of bottlenose dolphins (*Tursiops truncatus*) near the Bermuda Pedestal. MSc thesis, San Diego State University.

Klinck, H., S.L. Nieukirk, 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, and H. Slabbekoorn. 2017. Spatial avoidance to experimental increase of intermittent and continuous sound in two captive harbour porpoises. **Env. Poll.** 233:1024-1036.

Kok, A.C.M., L. Bruil, B. Berges, S. Sakinan, E. Debusschere, J. Reubens, D. de Haan, A. Norro, and H. Slabbekoorn. 2021. An echosounder view on the potential effects of impulsive noise pollution on pelagic fish around windfarms in the North Sea. **Environ. Poll.** 290:118063.

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.

Kyhn, L.A., D.M. Wisniewska, K. Beedholm, J. Tougaard, M. Simon, A. Mosbech, and P.T. Madsen. 2019. Basin-wide contributions to the underwater soundscape by multiple seismic surveys with implications for marine mammals in Baffin Bay, Greenland. **Mar. Poll. Bull.** 138:474-490.

Lageux, C.J. 2001. Status and Distribution of the Green Turtle, Chelonia mydas, in the Wider Caribbean Region, Pages 32-35 In K.L. Eckert and F.A.A. Grobois (eds.) Proceedings of the Regional Meeting: "Marine Turtle Conservation in the Wider Caribbean Region: A Dialogue for Effective Regional Management, Santo Domingo, 16-18 November 1999, WIDECAST, IUCN-MTSG, WWF, and UNEP-CEP.

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.** 32(2):643-663.

Landrø, M. and J. Langhammer. 2020. Comparing the broadband acoustic frequency response of single, clustered, and arrays of marine air guns. **Geophysics** 85(3):P27-P36.

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 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.

Leatherwood, S., D.K. Caldwell, and H.E. Winn. 1976. Whales, dolphins, and porpoises of the western North Atlantic. Vol. 396. US Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service.

Leeworthy, V.R., D. Schwarzmann, S. Hughes, J. Vaughn, C. Dato, and G. Padilla. 2018. Economic contribution of reef using visitor spending to the Puerto Rican economy. National Oceanic and Atmospheric Administration, Office of National Marine Sanctuaries. Silver Spring, MD. 23 p. Accessed November 2021 at https://www.ncei.noaa.gov/data/oceans/coris/library/NOAA/CRCP/NOS/ONMS/Other/pr_ecosystem_valuation/Economic_Contributions_accessible.pdf.

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. Am.** 112(5, Pt. 2):2314 (Abstr.).

León, Y. and C. Diez. 1999. Population structure of hawksbill turtles on a foraging ground in the Dominican Republic. Chelon. **Conserv. Biol**. 3:230-236.

León-Pérez, M.C., R.A. Armstrong, W.J. Hernández, A. Aguilar-Perera, and J. Thompson-Grim. 2020. Seagrass cover expansion of Caja de Muertos Island, Puerto Rico, as determined by long-term analysis of historical aerial and satellite images (1950-2014). **Ecol. Indic**. 117:106561.

Lesage, V., A. Omrane, T. Doniol-Valccroze, 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. Zydelis, 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.

Liberman, 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.

Lima, E.H.S.M., M.T.D. Melo, M.M. Severo, and P.C.R. Barata. 2008. Green Turtle Tag Recovery Further Links Northern Brazil to the Caribbean Region. Mar. Turtle Newsl. 119:14-15.

Lockyer, C.H. and S.G. Brown. 1981. The migration of whales. p. 105-137 In: D.J. Aidley (ed.), Animal migration. Soc. Exp. Biol. Sem. Ser. 13, Cambridge University Press, London, U.K.

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.

Luís, 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.

Luksenburg, J.A. 2014. Prevalence of external injuries in small cetaceans in Aruban waters, southern Caribbean. **PloS One** 9(2):e88988.

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.

MacKay, M.M. and C.E. Bacon. 2019. Rare and antagonistic interactions between short-finned pilot whales (*Globicephala macrorhynchus*) and fasting humpback whales (*Megaptera novaeangliae*) off western Puerto Rico. **Latin Am. J. Aquat. Mamm**. 14(1):34-40.

MacKay, M.M., B. Würsig, C.E. Bacon, and J.D. Selwyn. 2016. North Atlantic humpback whale (*Megaptera novaeangliae)* hotspots defined by bathymetric features off western Puerto Rico. **Can. J. Zool.** 94(7):517-527.

MacKay, M.M., C.E. Bacon, L. Bouveret, S. Fossette, and P.T. Stevick, P.T. 2019. Humpback whale (*Megaptera novaeangliae*) intra/inter-seasonal exchanges between Puerto Rico and the southeastern Caribbean. **Animal Behav. Cogn.** 6(2):98-104.

MacLeod, C.D., W.F. Perrin, R. Pitman, J. Barlow, L. Ballance, A. Amico, T. Gerrodette, G. Joyce, K.D. Mullin, D.L. Palka, and G.T. Waring. 2006. Known and inferred distributions of beaked whale species (Cetacea: Ziphiidae). **J. Cetacean Res. Manage.** 7(3):271.

Maguire, J.J., M. Sissenwine, J. Csirke, R. Grainger, and S. Garcia. 2006. The state of world highly migratory, straddling and other high seas fishery resources and associated species. FAO Fisheries Technical Paper. FAO, Rome, Italy.

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.

Marcovaldi, M.Â. 2001. Status and Distribution of the Olive Ridley Turtle, *Lepidochelys olivacea*, in the Western Atlantic Ocean. p. 52-56 *In:* K.L. Eckert and F.A.A. Grobois (eds.) Proceedings of the Regional Meeting: Marine Turtle Conservation in the Wider Caribbean Region: A Dialogue for Effective Regional Management, Santo Domingo, 16-18 November 1999, WIDECAST, IUCN-MTSG, WWF, and UNEP-CEP.

MarineTraffic. 2021. Live Map–AIS–Vessel Traffic and Positions. Accessed in July 2021 at http://www.marinetraffic.com.

Márquez, M.C. 2021. Shark week continues in Puerto Rico. Forbes. Accessed November 2021 at https://www.forbes.com/sites/melissacristinamarquez/2021/07/18/shark-week-continues-in-puerto-rico/?sh=14df0e93380a.

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.

Martin, S.B., K. Lucke, and D.R. Barclay. 2020. Techniques for distinguishing between impulsive and non-impulsive sound in the context of regulating sound exposure for marine mammals. **J. Acoust. Soc. Am.** 147(4):2159-2176.

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 Bénéden, 1864) in Pipa, North-eastern Brazil. **J. Mar. Biol. Assoc. U.K.** 2016:1-8.

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.

Matthews, L.P. and S.E. Parks. 2021. An overview of North Atlantic right whale acoustic behavior, hearing capabilities, and responses to sound. **Mar. Poll. Bull.** 173:113043.

Mattila, D.K. and P.J. Clapham. 1989. Humpback whales (*Megaptera novaeangliae*) and other cetaceans on Virgin Bank and in the northern Leeward Islands, 1985 and 1986. **Can. J. Zool.** 67:2201-2211.

Mattila, D.K., P.J. Clapham, O. Vásquez, and R.S. Bowman. 1994. Occurrence, population composition, and habitat use of humpback whales in Samana Bay, Dominican Republic. **Can. J. Zool.** 72(11):1898-1907.

Mattila, D.K., P.J. Clapham, S.K. Katona, and G.S. Stone. 1989. Population composition of humpback whales (*Megaptera novaeangliae*) on Silver bank, 1984. **Can. Zool.** 67:281-285.

Mauro, M., I. Pérez-Arjona, E.J. Belda Perez, M. Ceraulo, M. Bou-Cabo, T. Benson, V. Espinosa, F. Beltrame, S. Mazzola, M. Vazzana, and G. Buscano. 2020. The effect of low frequency noise on the behaviour of juvenile *Sparus aurata*. **J. Acoust. Soc. Am.** 147(6):3795-3807.

McAlpine, D.F. 2018. Pygmy and dwarf sperm whales. p. 786-788 *In:* B. Würsig, J.G.M. Thewissen, and K.M. Kovacs (eds.), Encyclopedia of Marine Mammals, 3rd ed. Academic Press/Elsevier, San Diego, CA. 1157 p.

McCarthy, E., D. Moretti, L. Thomas, N. DiMarzio, R. Morrissey, S. Jarvis, J. Ward, A. Izzi, and A. Dilley. 2011. Changes in spatial and temporal distribution and vocal behavior of Blainville's beaked whales (*Mesoplodon densirostris*) during multiship exercises with mid-frequency sonar. **Mar. Mamm. Sci.** 27(3):E206-E226.

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.

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., R.D. Day, K.M. Swadling, Q.P. Fitzgibbon, R.A. Watson, and J.M. Semmens. 2017. Widely used marine seismic survey air gun operations negatively impact zooplankton. **Nat. Ecol. Evol.** 1:0195.

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.

McGowan, A., A.C. Broderick, G. Frett, S. Gore, M. Hastings, A. Pickering, D. Wheatley, J. White, M.J. Witt, and B.J. Godley. 2008. Down but not out: marine turtles of the British Virgin Islands. **Anim. Conserv.** 11:92-103.

McHuron, E.A., L. Aerts, G. Gailey, O. Sychenko, D.P. Costa, M. Mangel, and L.K. Schwartz. 2021. Predicting the population consequences of acoustic disturbance, with application to an endangered gray whale population. **Ecol. Appl.** 31(8):p.e02440.

MCI (Marine Conservation Institute). 2021. The Marine Protection Atlas. Accessed November 2021 at https://mpatlas.org/.

McKenna, M.F., J. Calambokidis, E.M. Oleson, D.W. Laist, and J.A. Goldbogen. 2015. Simultaneous tracking of blue whales and large ships demonstrate limited behavioral responses for avoiding collision. **Endang. Species. Res.** 27:219-232.

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. and C.W. Potter. 1995. Recognizing two populations of the bottlenose dolphins (*Tursiops truncatus*) off the Atlantic coast of North America: morphological and ecological considerations. IBI Reports 5:31-44.

Meekan, M.G., C.W. Speed, R.D. McCauley, R. Fisher, M.J. Birt, L.M. Currey-Randall, J.M. Semmens et al. 2021. A large-scale experiment finds no evidence that a seismic survey impacts a demersal fish fauna. **Proceedings of the National Academy of Sciences** 118(30):e2100869118.

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.

Mellinger, D.K., C.D. Carson, and C.W. Clark. 2000. Characteristics of minke whale (*Balaenoptera acutorostrata*) pulse trains recorded near Puerto Rico. **Mar. Mamm. Sci.** 16(4):739-756.

Merten, W. and G. Rodriguez-Ferrer. 2014. First stranding and sighting of the false killer whale (*Pseudorca crassidens*) off Puerto Rico. **Caribb. J. Sci.** 48(1):59-62.

Meylan, A.B. 1999a. International movements of immature and adult hawksbill turtles (*Eretmochelys imbricata*) in the Caribbean region. **Chel. Conserv. Biol**. 3(2):189-194.

Meylan, A.B. 1999b. Status of the hawksbill turtle (*Eretmochelys imbricata*) in the Caribbean region. **Chel. Conserv. Biol**. 3(2):177-184.

Meylan, P.A., A.B. Meylan, and J.A. Gray. 2011. The ecology and migrations of sea turtles 8. Tests of the developmental habitat hypothesis. **Bull. Am. Museum Nat. History** 357:1-70.

Mignucci-Giannoni, A., S.L. Swartz, A. Martinez, C.M. Burks, and W.A. Watkins. 2003. First records of the pantropical spotted dolphin (*Stenella attenuata*) for the Puerto Rican Bank, with a review of the species in the Caribbean. **Caribb. J. Sci.** 39(3):381-391.

Mignucci-Giannoni, A.A., B. Pinto-Rodríguez, M. Velasco-Escuedero, R.A. Montoya-Ospina, H.M., Jimenez-Marrero, M.A. Rodríguez-López, E.H. Williamson, and D.K. Odell. 1999a. Cetacean strandings in Puerto Rico and the Virgin Islands. **J. Cetacean Res. Manage**. 1(2):191-198.

Mignucci-Giannoni, A.A., R.A. Montoya-Ospina, J.J. Pérez-Zayas, M.A. Rodríguez-López, and E.A. Williams. 1999b. New records of Fraser's dolphin (*Lagenodelphis hosei*) for the Caribbean. **Aquatic Mamm.** 25:15-20.

Mignucci-Giannoni, A.A., G.M. Toyos-González, J. Perez-Padilla, M.A. Rodríguez-López, and J. Overing. 1999c. Mass stranding of pygmy killer whales (*Feresa attenuata*) in the British Virgin Islands. **J. Mar. Biol. Assoc. UK** 80(2):759-760.Mignucci-Giannoni. A.A. 1996. Marine mammal strandings in Puerto Rico and the United States and British Virgin Islands. Ph.D. Thesis, University of Puerto Rico.

Mignucci-Giannoni, A.A. 1998. Zoogeography of cetaceans off Puerto Rico and the Virgin Islands. **Caribb. J. Sci**. 34(3-4):173-190.

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, 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, M.H., J.K. Carlson, P.W. Cooper, D.R. Kobayashi, M. Nammack, and J. Wilson. 2014. Status review report: scalloped hammerhead shark (*Sphyrna lewini*). Final Report to NMFS, Office of Protected Resources. 133 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.

Miller, P.J., S. Isojunno, E. Siegal, F.P.A. Lam, P.H. Kvadsheim, and C. Curé. 2022. Behavioral responses to predatory sounds predict sensitivity of cetaceans to anthropogenic noise within a soundscape of fear. *Proc. Nat. Acad. Sci. 119*(13):e2114932119.

Ministro de Medio Ambiente y Recursos Naturales. 2011. Lista de especies en peligro de extinción, amenzadaso protegidas de la República Dominicana, List Roja. Santo Domingo de Gúzman, República Dominicana.

Mitchell, E.D. 1975. Report on the meeting on small cetaceans, Montreal, April 1-11. **J. Fish. Res. Board Canada** 32:914-916.

Miyazaki, N. and W.F. Perrin. 1994. Rough-toothed dolphin *Steno bredanensis* (Lesson, 1828). p. 1-21 *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.

Mizroch, S.A., D.W. Rice, D. Zwiefelhofer, J. Waite, and W.L. Perryman. 2009. Distribution and movements of fin whales in the North Pacific Ocean. **Mamm. Rev.** 39(3):193-227.

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. doi:10.4401/ag-7089.

Moncada, F., C.E. Diez, M. Bermudez, G. Nodarse, and M. Barandiaran. 2020. Twenty-two years later: A long distance recapture of a green turtle (*Chelonia mydas*) tagged in Cuba and found in Puerto Rico. Mar. Turtle Newsl. 161:28-29.

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.

Morell, M., A.W. Vogl, L.L. Ijsseldijk, M. Piscitelli-Doshkov, L. Tong, S. Ostertag, M. Ferreira, N. Fraija-Fernandez, K.M. Colegrove, J.L. Puel, S.A. Raverty, and R.E. Shadvick. 2020. Echolocating whales and bats express the motor protein prestin in the inner ear: a potential marker for hearing loss. **Frontiers Vet. Sci.** 7:429. doi:10.3389/fvets.2020.00429

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.

Morris, C.J., D. Cote, B. Martin, R. Saunders-Lee, M. Rise, J. Hanlon, J. Payne, P.M. Regular, D. Mullowney, J.C. Perez-Casanova, M.G. Persiak, J. Xu, V. Han, D. Kehler, J.R. Hall, S. Lehnert, E. Gonzalez, S. Kumar, I. Bradbury, and N. Paddy. 2021. As assessment of seismic surveys to affect snow crab resources. St. John's, NL, 92 p. Environmental Research Fund Report No. 200.

Morris, C.J., D. Cote, S.B. Martin, and D. Mullowney. 2020. Effects of 3D seismic surveying on snow crab fishery. **Fish. Res.** 232:105719.

Mortensen, L.O., M.E. Chudzinska, H. Slabbekoorn, and F. Thomsen. 2021. Agent-based models to investigate sound impact on marine animals: bridging the gap between effects on individual behaviour and population level consequences. **Oikos** 130(7):1074-1086

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. Bröker. 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.

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. 2018. Four odontocete species change hearing levels when warned of impending loud sound. **Integr. Zool.** 13(2):160-165.

NAMMCO (North Atlantic Marine Mammal Commission). 2016. Marine mammals. Accessed in January 2021 at https://nammco.no/marinemammals/.

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.

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.

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.

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). 1979. Designated critical habitat; Determination of critical habitat for leatherback sea turtle. **Fed. Reg.** 44(58, 23 March):17710-17711.

NMFS. 1998. Designated critical habitat; green and hawksbill sea turtle. **Fed. Reg.** 63(170, 2 Sept.):46693-46701.

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. Reg.** 66(26, 7 Feb.):9291-9298.

NMFS. 2008. Endangered and threatened species; critical habitat for threatened elkhorn and staghorn corals. **Fed. Reg.** 73(229, 26 Nov.):72210-72240.

NMFS. 2009. Smalltooth sawfish (*Pristis pectinata*) Recovery Plan. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service. 102 p.

NMFS. 2011. Endangered and threatened species; determination of nine distinct population segments of loggerhead sea turtles as endangered or threatened; final rule. **Fed. Reg.** 76(184, 22 Sept.):58868-58952.

NMFS. 2013. 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 October 2021 at https://www.fisheries.noaa.gov/national/marine-mammal-protection/environmental-impact-statement-eis-effects-oil-and-gas-activities.

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. Depart. 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. Reg.** 81(174, 8 Sept.):62260-62320.

NMFS. 2016c. Endangered and threatened wildlife and plants; final rule to list eleven Distinct Population Segments of the green sea turtle (*Chelonia mydas*) as endangered or threatened and revision of current listings under the Endangered Species Act. **Fed. Reg.** 81(66, 6 Apr.):20058-20090.

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. Recovery outline for the Nassau grouper (*Epinephelus striatus*). U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service. 8 p.

NMFS. 2018c. Recovery outline for the oceanic whitetip shark (*Carcharhinus longimanus*). U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service. 7 p.

NMFS. 2019a. Takes of marine mammals incidental to specified activities; taking marine mammals incidental to a marine geophysical survey in the Gulf of Alaska. **Fed. Reg.** 84(113, 12 June):27246-27270.

NMFS. 2019b. Takes of marine mammals incidental to specified activities; taking marine mammals incidental to a marine geophysical survey in the Northeast Pacific Ocean. **Fed. Reg.** 84(140, 22 July):35073-35099.

NMFS. 2020. Endangered and threatened species; critical habitat for threatened Caribbean corals. **Fed. Reg.** 85(229, 27 Nov.):76302-76357.

NMFS. 2022. Draft U.S. Atlantic and Gulf of Mexico marine mammal stock assessments: 2022. NOAA Tech. Memo. Accessed July 2023 at https://www.fisheries.noaa.gov/s3/2023-01/Draft%202022%20Atlantic%20SARs_final.pdf

NMFS and USFWS (U.S. Fish and Wildlife Service). 2013. Hawksbill sea turtle (*Eretmochelys imbricata*) 5-year review: summary and evaluation. Nat. Mar. Fish. Service, Silver Spring, MD. 89 p.

NMFS and USFWS. 2020. Endangered Species Act status review of the leatherback turtle (*Dermochelys coriacea*). Report to the National Marine Fisheries Service Office of Protected Resources and U.S. Fish and Wildlife Service.

NOAA (National Oceanographic and Atmospheric Administration). 2002. Magnuson-Stevens Act Provisions; Essential Fish Habitat (EFH). **Fed. Reg.** 67(12; 17 Jan.):2343-2382.

NOAA. 2009. Coral reef habitat assessment for U.S. Marine Protected Areas: Commonwealth of Puerto Rico. National Oceanic and Atmospheric Administration, NOAA's National Ocean Service Management & Budget Office Special Projects. 43 p. + appendices. Accessed November 2021 at https://www.coris.noaa.gov/activities/habitat_assessment/puerto_rico.pdf.

NOAA. 2020a. Essential Fish Habitat – U.S. Caribbean. Accessed January 2022 at https://media.fisheries.noaa.gov/dam-migration/efh_cfmc_ver092020.pdf.

NOAA. 2020b. Wrecks and obstructions database. National Oceanic and Atmospheric Administration U.S. Department of Commerce. Accessed November 2021 at https://nauticalcharts.noaa.gov/data/wrecks-and-obstructions.html.

NOAA. 2020c. Taking and importing marine mammals; taking marine mammals incidental to Southeast Fisheries Science Center Fisheries Research. **Fed. Reg.** 85(88, 6 May):27028-27083.

NOAA. 2021a. GIS Data for Essential Fish Habitat. Accessed December 2021 at https://www.habitat.noaa.gov/protection/efh/newInv/maps/caribbean_efh-min.png

NOAA. 2021b. GIS Data for Habitat Areas of Particular Concern. Accessed December 2021 at https://www.habitat.noaa.gov/protection/efh/newInv/hapc_content.html

NOAA. 2022a. Giant manta ray (*Manta birostris*). U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service. Accessed in January 2020 at https://www.fisheries.noaa.gov/species/giant-manta-ray.

NOAA. 2022b. Smalltooth sawfish (*Pristis pectinata*). U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service. Accessed in January 2020 at https://www.fisheries.noaa.gov/species/smalltooth-sawfish.

NOAA. 2022c. Oceanic whitetip shark (*Carcharhinus longimanus*). U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service. Accessed in January 2020 at https://www.fisheries.noaa.gov/species/oceanic-whitetip-shark.

NOAA. 2023. Active and closed unusual mortality events. Accessed in March 2023 at https://www.fisheries.noaa.gov/national/marine-life-distress/active-and-closed-unusual-mortality-events.

NOAA Coral Program. 2021. National Coral Reef Monitoring Plan. NOAA Coral Reef Conservation Program. Silver Spring, MD. 34 p. Accessed November 2021 at https://repository.library.noaa.gov/view/noaa/32748.

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., 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.** 120:235-244.

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., L.H. Thorne, D.W. Johnston, and P.L. Tyack. 2007. Responses of cetaceans to anthropogenic noise. **Mamm. Rev.** 37(2):81-115.

NPS (National Park Service). 2021. Maritime heritage of Puerto Rico. National Park Service U.S. Department of the Interior. Accessed November 2021 at https://www.nps.gov/articles/000/martime-heritage-of-puerto-rico.htm.

NRC (National Research Council). 2005. Marine mammal populations and ocean noise/Determining when noise causes biologically significant effects. U.S. Nat. Res. Counc., 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 (National Science Foundation 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.

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.

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). 2021. Data from the Ocean Biogeographic Information System. Intergovernmental Oceanographic Commission of UNESCO. Accessed July 2021 at http://www.iobis.org.

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.

Olson, P.A. 2018. Pilot whales *Globicephala melas* and *G. macrorhynchus*. p. 701-705 *In:* B. Würsig, J.G.M. Thewissen, and K.M. Kovacs (eds.), Encyclopedia of Marine Mammals, 3rd Edition. Academic Press/Elsevier, San Diego, CA. 1157 p.

PADI (Professional Association of Diving Instructors). 2021. Top dive sites in Puerto Rico. Accessed November 2021 at https://www.padi.com/dive-sites/puerto-rico/?ordering=-rating%2C-number_reviews.

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.

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.

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., 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.

Parry, G.D., S. Heislers, 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.

Patrício, A.R., X. Velez-Zuazo, C.E. Diez, R. van Dam, and A.M. Sabat. 2011. Survival probability of immature green turtles in two foraging grounds at Culebra, Puerto Rico. **Mar. Ecol. Prog. Ser.** 440:217-227.

Patrício, A.R., X. Vélez-Zuazo, R.P. van Dam, and C.E. Diez. 2017. Genetic composition and origin of juvenile green turtles foraging at Culebra, Puerto Rico, as revealed by mtDNA. **Lat. Am. J. Aquat. Res.** 45:506-520.

Patrício, R., C.E. Diez, and R.P. van Dam. 2014. Spatial and temporal variability of immature green turtle abundance and somatic growth in Puerto Rico. **Endang. Spec. Res.** 23:51-62.

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, 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.

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.

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. Env. Res.** 38:93-113.

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.

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.

Perrin, W.F. 2018a. Pantropical spotted dolphin *Stenella attenuata*. p. 676-678 *In:* B. Würsig, J.G.M. Thewissen, and K.M. Kovacs (eds.), Encyclopedia of Marine Mammals, 3rd ed. Academic Press/Elsevier, San Diego, CA. 1157 p.

Perrin, W.F. 2018b. Spinner dolphin *Stenella longirostris*. p. 925-928 *In:* B. Würsig, J.G.M. Thewissen, and K.M. Kovacs (eds.), Encyclopedia of Marine Mammals, 3rd ed. Academic Press/Elsevier, San Diego, CA. 1157 p.

Perrin, W.F. 2018c. Common dolphin *Delphinus delphis*. p. 205-209 *In:* B. Würsig, J.G.M. Thewissen, and K.M. Kovacs (eds.), Encyclopedia of Marine Mammals, 3rd ed. Academic Press/Elsevier, San Diego, CA. 1157 p.

Perrin, W.F., D.K. Caldwell, and M.C. Caldwell. 1994a. Atlantic spotted dolphin *Stenella frontalis* (G. Cuvier, 1829). p. 173-190 *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.

Perrin, W.F., C.E. Wilson, and F.I. Archer II. 1994b. 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.

Perryman, W.L. and K. Danil. 2018. Melon-headed whale *Peponocephala electra*. p. 593-595 *In:* B. Würsig, J.G.M. Thewissen, and K.M. Kovacs (eds.), Encyclopedia of Marine Mammals, 3rd Edition. Academic Press/Elsevier, San Diego, CA. 1157 p.

Pichegru, L., R. Nyengera, A.M. McInnes, and P. Pistorius. 2017. Avoidance of seismic survey activities by penguins. **Sci. Rep.** 7:16305.

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.

Piniak, W.E. and K.L. Eckert. 2011. Sea turtle nesting habitat in the Wider Caribbean Region. **Endang. Spec. Res.** 15:129-141.

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., 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.

Pirotta, E., M. Mangel, D.P. Costa, B. Mate, J.A. Goldbogen, D.M. Palacios, L.A. Hückstädt, 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.

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., 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.

Pitman, R. 2018. Mesoplodon beaked whales *Mesoploldon* spp. p. 595-602 *In:* B. Würsig, J.G.M. Thewissen, and K.M. Kovacs (eds.), Encyclopedia of Marine Mammals, 3rd Edition. Academic Press/Elsevier, San Diego, CA. 1157 p.

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.

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. 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.V., A.Y. Supin, A.P. Gvozdeva, D.I. Nechaev, M.B. Tarakanov, and E.V. Sysueva. 2020. Spatial release from masking in a bottlenose dolphin *Tursiops truncatus*. **J. Acoust. Soc. Am.** 147(3):1719-1726.

Popper, A.N. 2009. Are we drowning out fish in a sea of noise? **Mar. Sci.** 27:18-20.

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. and A.D. Hawkins. 2019. An overview of fish bioacoustics and the impacts of anthropogenic sounds on fishes. **J. Fish Biol.** 94:692-713.

Popper, A.N. and A.D. Hawkins. 2021. Fish hearing and how it is best determined. **ICES J. Mar. Sci.** 78(7):2325-2336.

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., A.D. Hawkins, O. Sand, and J.A. Sisneros. 2019a. Examining the hearing abilities of fishes. **J. Acoust. Soc. Am.** 146(2):948-955.

Popper, A.N., A.D. Hawkins, and M.C. Halvorsen. 2019b. Anthropogenic sound and fishes. A report prepared for the Washington State Department of Transportation, Olympia, WA. http://www.wsdot.wa.gov/research/reports/800/anthropogenic-sound-and-fishes.

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.

Popper, A.N., L. Hice-Dunton, E. Jenkins, D.M. Higgs, J. Krebs, A. Mooney, A. Rice, L. Roberts, F. Thomsen, K. Vigness-Raposa, D. Zeddies, and K.A. Williams. 2022. Offshore wind energy development: research priorities for sound and vibration effects on fish and aquatic invertebrates. **J. Acoust. Soc. Am.** 151(1):205-215.

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.

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.** 24(4):1708-1721.

Putman, N.F., E.E. Seney, P. Verley, D.J. Shaver, M.C. López-Castro, M. Cook, V. Guzmán, B. Brost, S.A. Ceriani, R. Mirón, L.J. Peña, M. Tzeek, R.A. Valverde, C.C.G. Cantón, L. Howell, J.A. R. Ley, M.C. Tumlin, W.G. Teas, C.W. Caillouet Jr, E. Cuevas, B.J. Gallaway, P.M. Richards, and K.L. Mansfield. 2019. Predicted distributions and abundances of the sea turtle 'lost years' in the western North Atlantic Ocean. **Ecography** 42:1-12.

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.

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.

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., 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.

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., K. McClellan, and T.B. Werner. 2013. Marine mammal bycatch in gillnet and other entangling net fisheries, 1990 to 2011. **Endang. Species Res.** 20: 71-97.

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.

Reilly, S.B. and V.G. Thayer. 1990. Blue whale (*Balaenoptera musculus*) distribution in the eastern tropical Pacific. **Mar. Mamm. Sci.** 6(4):265–277.

Revuelta, O. 2014. Biology and conservation of marine turtle nesting in the Dominican Republic. Ph.D. Thesis, Uniersitat De València.

Revuelta, O., Y.M. León, P. Feliz, B.J. Godley, J.A. Raga, and J. Tomás. 2012. Protected areas host important remnants of marine turtle nesting stocks in the Dominican Republic. **Oryx** 46:348-358.

Revuelta, O., L. Hawkes, Y.M. León, B.J. Godley, J.A. Raga, and J. Tomás. 2015. Evaluating the importance of marine protected areas for the conservation of hawksbill turtles nesting in the Dominican Republic. **Endang. Spec. Res.** 27:169-180.

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.

Rice, D.W. 1998. Marine mammals of the world, systematics and distribution. Spec. Publ. 4. Soc. Mar. Mammal., Allen Press, Lawrence, KS. 231 p.

Richards, P.M., S.P. Epperly, S.S. Heppell, R.T. King, C.R. Sasso, F. Moncada, G. Nodarse, D.J. Shaver, Y. Medina, and J. Zurita. 2011. Sea turtle population estimates incorporating uncertainty: a new approach applied to western North Atlantic loggerheads *Caretta caretta*. **Endang. Spec. Res**. 15(2):151-158.

Richardson, A.J., R.J. Matear, and A. Lenton. 2017. Potential impacts on zooplankton of seismic surveys. CSIRO, Australia. 34 p.

Richardson, P.B., M.C. Calosso, J. Claydon, W. Clerveaux, B.J. Godley, Q. Phillips, S. Ranger, A. Sanghera, T.B. Stringell, and A.C. Broderick. 2010. Suzie the green turtle: 6000 kilometres for one clutch of eggs. Mar. Turtle Newsl. 127:26-27.

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.).

Riddle, H. 2018. Your guide to whale watching in the Caribbean. Beach. Accessed December 2021 at https://www.beach.com/activities/whale-watching-caribbean/#:~:text=You%20can't%20go%20just, watching%20on%20your%20beach%20vacation

Rincon-Diaz, M.P., C.E. Diez, R.P. Van Dam, and A.M. Sabat. 2011a. Foraging selectivity of the hawksbill sea turtle (*Eretmochelys imbricata*) in the Culebra Archipelago, Puerto Rico. **J. Herpet.** 45(3):277-282.

Rincon-Diaz, M.P., C.E. Diez, R.P. Van Dam, and A.M. Sabat. 2011b. Effect of food availability on the abundance of juvenile hawksbill sea turtles (*Eretmochelys imbricata*) in inshore aggregation areas of the Culebra Archipelago, Puerto Rico. **Chel. Conserv. Biol.** 10(2):213-221.

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.

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.

Roberts, J.J., T.M. Yack, and P.N. Halpin. 2023. Marine mammal density models for the U.S. Navy Atlantic Fleet Training and Testing (AFTT) study area for the Phase IV Navy Marine Species Density Database (NMSDD). Document version 1.3. Report prepared for Naval Facilities Engineering Systems Command, Atlantic by the Duke University Marine Geospatial Ecology Lab, Durham, NC. Accessed July 2023 at https://seamap.env.duke.edu/models/Duke/AFTT/

Roberts, L. and M. Elliott. 2017. Good or bad vibrations? Impacts of anthropogenic vibration on the marine epibenthos. **Total Environ.** 595:255-268.

Roberts, L., S. Cheesman, T. Breithaupt, and M. Elliott. 2015. Sensitivity of the mussel *Mytilus edulis* to substrate-borne vibration in relation to anthropogenically generated noise. **Mar. Ecol. Prog. Ser.** 538:185-195.

Roberts, L., S. Cheesman, M. Elliott, and T. Breithaupt. 2016. Sensitivity of *Pagurus bernhardus* (*L.*) to substrate-borne vibration and anthropogenic noise. **J. Exp. Mar. Biol. Ecol. 474**:185-194.

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.

Roden, C.L. and K.D. Mullin. 2000. Sightings of cetaceans in the northern Caribbean Sea and adjacent waters, winter 1995. **Caribb. J. Sci.** 36(3-4):280-288.

Rodriguez-Ferrer, G., R. Reyes, N.M. Hammerman, and J.E. García-Hernández. 2018. Cetacean sightings in Puerto Rican waters: including the first underwater photographic documentation of a minke whale (*Balaenoptera* *acutorostrata*). **Latin Am. J. Aquatic Mamm.** 13(1-2):26-36.

Rodríguez-López, M.A. and A.A. Mignucci-Giannoni. 1999. A stranded pygmy killer whale (*Feresa attenuata*) in Puerto Rico. **Aquatic Mamm.** 25:119-121.

Rogers, P., E. Debusschere, D. de Haan, B. Martin, B., and H.W. Slabbekoorn. 2021. North Sea soundscapes from a fish perspective: directional patterns in particle motion and masking potential from anthropogenic noise. **J. Acoust. Soc. Am.** 150(3):2174-2188.

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.

Romero, I. 2018. PR Government nullifies classification of seven nature reserves. Repeating Islands. Accessed November 2021 at https://repeatingislands.com/2018/07/22/pr-government-nullifies-classification-of-seven-nature-reserves/.

Rosario-Delestre, R.J., M.A. Rodríguez-López, A.A. Mignucci-Giannoni, and J.G. Mead. 1999. New records of beaked whales (*Mesoplodon* spp.) for the Caribbean. **Caribb. J. Sci.** 35(1-2):144-148.

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.

Rutenko, A.N., M.M. Zykov, V.A. Gritsenko, M.Y. Fershalov, M.R. Jenkerson, R. Racca, and V.E. Nechayuk 2022. Real-time acoustic monitoring with telemetry to mitigate potential effects of seismic survey sounds on marine mammals: a case study offshore Sakhalin Island. **Env. Monit. Assess.** 194 (Suppl. 1):745.

Sadovy de Mitcheson, Y. 2012. Status update: the Nassau Grouper, *Epinephelus striatus*. Final Report to the Caribbean Fishery management Council. 70 p.

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.

Sanders, I.M., J.C. Barrios-Santiago, and R.S. Appeldoorn. 2005. Distribution and relative abundance of humpback whales off western Puerto Rico during 1995-1997. **Caribb. J. Sci.** 41(1):101-107.

Sarnocińska, J., J. Teilmann, J.D. Balle, F.M. van Beest, M. Delefosse, and J. Tougaard. 2020. Harbor porpoise (*Phocoena phocoena*) reaction to a 3D seismic airgun survey in the North Sea. **Front. Mar. Sci.** 6: 824.

Savage, K. 2017. Alaska and British Columbia Large Whale Unusual Mortality Event Summary Report. NOAA Fisheries, Juneau, AK. 42 p.

Schärer-Umpierre, M.T., D. Mateos-Molina, R. Appeldoorn, I. Bejarano, E.A. Hernández-Delgado, R.S. Nemeth, M.I. Nemeth, M. Valdés-Pizzini, and T.B. Smith. 2014. Marine managed areas and associated fisheries in the US Caribbean. **Adv. Mar. Biol.** 69:129-152.

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.

Sea Around Us. 2021. Sea Around Us Project. Accessed December 2021 at http://www.seaaroundus.org

SeaRates. 2023. Sea ports of Puerto Rico. Accessed Spril 2023 at https://www.searates.com/maritime/puerto_rico.

Seminoff, J.A., C.D. Allen, G.H. Balazs, P.H. Dutton, T. Eguchi, H.L. Haas, S.A. Hargrove, M.P. Jensen, D.L. Klemm, A.M. Lauritsen, S.L. MacPherson, P. Opay, E.E. Possardt, S.L. Pultz, E.E. Seney, K.S. Van Houtan, and R.S. Waples. 2015. Status Review of the Green Turtle (*Chelonia mydas*) Under the U.S. Endangered Species Act. NOAA Technical Memorandum, NOAA-NMFS-SWFSC-539. 571 p.

Sergeant, D.E. 1977. Stocks of fin whales *Balaenoptera physalus* L. in the North Atlantic Ocean. Rep. Int. Whal. Comm. 27:460-473.

Shenker, J.M., E.D. Maddox, E. Wisinski, A. Pearl, S.R. Thorrold, and N. Smith. 1993. Onshore transport of settlement-stage Nassau grouper (*Epinephelus striatus*) and other fishes in Exuma Sound, Bahamas. **Mar. Ecol. Progr. Ser.** 98:31-43.

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. Atack, 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.

Sills, J.M., B. Ruscher, R. Nichols, B.L. Southall, and C. Reichmuth. 2020. Evaluating temporary threshold shift onset levels for impulsive noise in seals. **J. Acoust. Soc. Am.** 148(5):2973-2986.

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.

Slabbekoorn, H., J. Dalen, D. de Haan, H.V. Winter, C. Radford, M.A. Ainslie, K.D. Heaney, T. van Kooten, L. Thomas, and J. Harwood. 2019. Population-level consequences of seismic surveys on fishes: An interdisciplinary challenge. **Fish Fisheries** 20 (4):653-685.

Smith, T.D., J. Allen, P.J. Clapham, P.S. Hammond, S. Katona, F. Larsen, J. Lien, D. Mattila, P. Palsbøll, J. Sigurjónsson, P.T. Stevick and N. Øien. 1999. An ocean-basin-wide mark-recapture study of the North Atlantic humpback whale (*Megaptera novaeangliae*). **Mar. Mamm. Sci.** 15(1):1-32.

Soanes, L.M., J.A. Bright, D. Carter, M.P. Dias, T. Fleming, K. Gumbs, G. Hughes, F. Mukhida, and J.A. Green. 2016. Important foraging areas of seabirds from Anguilla, Caribbean: Implications for marine spatial planning. **Mar. Pol.** 70:85-92.

Solan, M., C. Hauton, J.A. Godbold, C.L. Wood, T.G. Leighton, and P. White. 2016. Anthropogenic sources of underwater sound can modify how sediment-dwelling invertebrates mediate ecosystem properties. **Sci. Rep.** 6:20540.

Solé, G. 1994. Migration of the Chelonia mydas population from Aves Island. p. 283-286 *In:* K.A. Bjorndal, A.B. Bolten, D.A. Johnson, and P.J. Eliazar (compilers), Proceedings of the 14th Annual Symposium on Sea Turtle

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.

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., 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.

Southall, B.L. 2021. Evolutions in marine mammal noise exposure criteria. **Acoustics Today** 17(2):52-60.

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 January 2022 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.

Southall, B.L., D.P. Nowacek, A.E. Bowles, V. Senigaglia, L. Bejder, and P.L. Tyack. 2021. Marine mammal noise exposure criteria: assessing the severity of marine mammal behavioral responses to human noise. **Aquatic Mamm.** 47(5):421-464.

Spotila, J.R. 2004. Sea turtles: a complete guide to their biology, behavior, and conservation. The Johns Hopkins University Press and Oakwood Arts. Baltimore and London.

Stevick, P.T., J. Allen, M. Berube, P.J. Clapham, S.K. Katona, F. Larsen, J. Lien, D.K. Mattila, P.J. Palsbøll, J. Robbins, J. Sigurjónsson, T.D. Smith, Øien, and P.S. Hammond. 2003b. Segregation of migration by feeding ground origin in North Atlantic humpback whales (*Megaptera novaeangliae*). **J. Zool. Lond.** 259:231-237.

Stevick, P.T., J. Allen, P.J. Clapham, N. Friday, S.K. Katona, F. Larsen, J. Lien, D.K. Mattila, P.J. Palsbøll, J. Sigurjónsson, T.D. Smith, N. Øien, and P.S. Hammond. 2003a. North Atlantic humpback whale abundance and rate of increase four decades after protection from whaling. **Mar. Ecol. Prog. Ser.** 258:263-272.

Stevick, P.T., L. Bouveret, N. Gandilhon, C. Rinaldi, R. Rinaldi, F. Broms, C. Carlson, A.W. Kennedy, N. Ward, and F. Wenzel. 2018. Migratory destinations and timing of humpback whales in the southeastern Caribbean differ from those off the Dominican Republic. **J. Cetac. Res. Manage.** 18:127-133.

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.

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.

Stoner, A.W. 1997. The status of queen conch, *Strombus gigas*, research in the Caribbean. **Mar. Fish. Rev.** 59(3): 14-33.

Stoner, A.W., R.A. Glazer, and P.J. Barile. 1996. Larval supply to queen conch nurseries: relationships with recruitment process and population size in Florida and the Bahamas. **J. Shellfish Res.** 15(2):407-420.

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.

Swartz, S.L., A. Martinez, J. Stamates, C. Burks, and A.A. Mignucci-Giannoni. 2002. Acoustic and visual survey of cetaceans in the waters of Puerto Rico and the Virgin Islands: February–March 2001. NOAA Technical Memorandum NMFS-SEFSC-463.

Swartz, S.L., A. Martinez, T. Cole, P.J. Clapham, M.A. McDonald, J.A. Hildebrand, E.M. Oleson, C. Burks, and J. Barlow. 2001. Visual and acoustic survey of humpback whales (*Megaptera novaeangliae*) in the eastern and southern Caribbean Sea. NOAA Technical Memorandum NMFS-SEFSC-456.

SWoT (State of the World's Sea Turtles). 2011. SWoT Feature map: green turtle satellite telemetry and genetic stocks. p. 32-33 *In:* R.B. Mast, B.J. Hutchinson, B. Wallace, L. Yarnell, and S. Hoyt (eds.) The State of the World's Sea Turtles, Report Vol. VI. State of the World's Sea Turtles, Arlington, VA.

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.

Tejo, H.M.D. 2021. History and conservation status of the Antillean manatee *Trichechus manatus manatus* in Hispaniola. **Oryx** 55(2):284-293.

Téllez, R., A.A. Mignucci-Giannoni, and S. Caballero. 2014. Initial description of short-finned pilot whale (*Globicephala macrorhynchus*) genetic diversity from the Caribbean. **Bioch. Syst. Ecol.** 56:196-201.

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.

Tervo, O.M., S.B. Blackwell, S. Ditlevsen, A.S. Conrad, A.L. Samson, E. Garde, R.G. Hansen, and M.P. Heide-Jørgensen. 2021. Narwhals react to ship noise and airgun pulses embedded in background noise. **Biol. Lett.** 17(11): 20210220.

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.

Thode, A.M., S.B. Blackwell, A.S. Conrad, K.H. Kim, T. Marques, L. Thomas, C.S. Oedekoven, D. Harris, and K. Bröker. 2020. Roaring and repetition: How bowhead whales adjust their call density and source level (Lombard effect) in the presence of natural and seismic airgun survey noise. **J. Acoust. Soc. Am.** 147(3):2061-2080.

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.

Tomás, J., B.J. Godley, Y.M. León, O. Revuelta, and J.A. Raga. 2011. Sea turtle conservation in the Dominican Republic: the importance of National Parks. **Testudo** 7:32-38.

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.

Trigg, L.E., F. Chen, G.I. Shapiro, S.N. Ingram, C. Vincent, D. Thompson, D.J. Russell, M.I. Carter, and C.B. Embling. 2020. Predicting the exposure of diving grey seals to shipping noise. **J. Acoust. Soc. Am.** 148(2):1014-1029.

Tröeng, S., D.R. Evans, E. Harrison, and C.J. Lagueux. 2005. Migration of green turtles *Chelonia mydas* from Tortuguero, Costa Rica. **Mar. Biol.** 148(2):435-447.

Tyack, P.L. and L. Thomas. 2019. Using dose-response functions to improve calculations of the impact of anthropogenic noise. **Aquatic Conserv. Mar. Freshw. Ecosyst.** 29(S1):242-253.

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.

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.

UNEP-CEP (United Nations Environment Programme-Caribbean Environment Programme). 2016. Action plan for the conservation of marine mammals (MMAP) in the Wider Caribbean Region. The Protocol Concerning Specially Protected Areas and Wildlife (SPAW) of the Wider Caribbean Region. 2 p. Accessed December 2021 at https://www.unep.org/cep/resources/factsheet/marine-mammal-factsheet.

UNEP-CEP. 2021a. Cartagena Convention. Caribbean Environment Programme. Accessed November 2021 at https://www.unep.org/cep/who-we-are/cartagena-convention.

UNEP-CEP. 2021b. Marine Protected Ares in the Caribbean. CaMPAM Network and Forum Caribbean MPA Map and Geospatial Data Ver 2.0. Accessed November 2021 at https://sites.google.com/cep.unep.org/campamgeospatialdatabase/home/geospatial-databases/caribbean-mpa-map.

UNEP-WCMC and IUCN. 2021. Protected Planet: The World Database on Protected Areas (WDPA) and World Database on Other Effective Area-based Conservation Measures (WD-OECM). Accessed November 2021 at https://www.protectedplanet.net/en.

US Customs and Border Protection. 2023. Locate a port of entry in Puerto Rico. Department of Homeland Security. Accessed April 2023 at https://www.cbp.gov/contact/ports/PR.

USCG (United States Coast Guard). 2021. Amver density plot display. United States Coast Guard, U.S. Dept. of Homeland Security. Accessed in July 2021 at http://www.amver.com/Reports/DensityPlots.

USCG. 2023. AMVER density plot display. United States Coast Guard, US Department of Homeland Security. Accessed April 2023 at https://www.amver.com/Reports/DensityPlots.

USFWS (U.S. Fish and Wildlife Service). 2007. West Indian Manatee (*Trichechus manatus*). 5-Year Review: summary and evaluation. U.S. Fish and Wildlife Service Caribbean Field Office, Puerto Rico.

USFWS. 2010. Caribbean roseate tern and North Atlantic roseate tern (*Sterna dougallii dougallii*). Caribbean Ecological Services Field Office, Boquerón, Puerto Rico, Northeast Region, New England Field Office Concord, NH.

USFWS. 2020. Roseate Tern Northeastern North American Population (*Sterna dougallii dougallii*) 5-Year Review: Summary and Evaluation. U.S. Fish and Wildlife Service New England Field Office North Atlantic-Appalachian Region Concord, NH. Accessed December 2021 at https://ecos.fws.gov/docs/five_year_review/doc6559.pdf.

USFWS. 2021. Endangered species. U.S. Fish and Wildlife Service. Accessed November 2021 at https://www.fws.gov/endangered/?s8fid2=112761032791&s8fid2=112762573891&searchTerm=brown+pelican.

USGS (US Geological Survey). 2013. Record of Decision for 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. 41 p.

USGS. 2019. Coastal and Marine Hazards and Resources Program decadal strategic plan. Accessed November 2021 at https://wim.usgs.gov/geonarrative/cmhrp/.

Valverde, R.A. and K.R. Holzwart. 2017. Sea turtles of the Gulf of Mexico. p. 1189-1351 *In:* C. Ward (ed.). Habitats and biota of the Gulf of Mexico: before the Deepwater Horizon oil spill. Springer, New York, NY.

van Beest, F.M., J. Teilmann, L. Hermannsen, A. Galatius, L. Mikkelsen, S. Sveegaard, J.D. Balle, R. Dietz, and 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.

Van Dam, R.P. and C.E. Diez. 1998. Home range of immature hawksbill turtles *Eretmochelys imbricata* (Linnaeus) at two Caribbean islands. **J. Exp. Mar. Biol. Ecol.** 220:15-24.

Van Dam, R.P., C.E. Diez, G.H. Balazs, L.A. Colón Colón, W.O. McMillan, and B. Schroeder. 2008. Sex-specific migration patterns of hawksbill turtles breeding at Mona Island, Puerto Rico. **Endang. Spec. Res.** 4:85-94.

van der Knaap, I., J. Reubens, L. Thomas, M.A. Ainslie, H.V. Winter, J. Hubert, B. Martin, and H. Slabbekorn. 2021. Effects of a seismic survey on movement of free-ranging Atlantic cod. **Current Biol.** 31(7):1555-1562.

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.

Varghese, H.K., J. Miksis-Olds, N. DiMarzio, K. Lowell, E. Linder, L. Mayer, and D. Moretti. 2020. The effect of two 12 kHz multibeam mapping surveys on the foraging behavior of Cuvier's beaked whales off of southern California. **J. Acoust. Soc. Am.** 147(6):3849-3858.

Varghese, H.K., K. Lowell, J. Miksis-Olds, N. DiMarzio, D. Moretti, and L. Mayer. 2021. Spatial analysis of beaked whale foraging during two 12 kHz multibeam echosounder surveys. **Front. Mar. Sci.** 8:654184.

Vazzana, M., M. Mauro, M. Ceraulo, M. Dioguardi, E. Papale, S. Mazzola, V. Arizza, F. Beltrame, L. Inguglia, and G. Buscaino. 2020. Underwater high frequency noise: biological responses in sea urchin *Arbacia lixula* (Linnaeus, 1758). **Comp. Biochem. Physiol. Part A: Mol. Integ. Physiol.** 242:110650.

Velez-Zuazo, X., W.D. Ramos, R.P. Van Dam, C.E. Diez, A. Abreu-Grobois, and W.O. MCMillan. 2008. Dispersal, recruitment and migratory behaviour in a hawksbill sea turtle aggregation. **Mol. Ecol.** 17:839-853.

Víkingsson, G.A., T. Gunnlaugsson, and C. Pampoulie. 2010. A proposal to initiate a pre-implementation assessment of sei whales in the Central North Atlantic. Working Pap. SC/62/RMP2. Int. Whal. Comm., Cambridge, U.K. 27 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.

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.

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.

Wale, M.A., R.A. Briers, and K. Diele. 2021. Marine invertebrate anthropogenic noise research – trends in methods and future directions. **Mar. Poll. Bull.** 173:112958.

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.

Wallace, B.P., R.L. Lewison, S.L. McDonald, R.K. McDonald, C.Y. Kot, S. Kelez, R.K. Bjorkland, E.M. Finkbeiner, S. Helmbrecht, and L.B. Crowder. 2010. Global patterns of marine turtle bycatch. **Conservation Letters** 3: 131-142.

Ward, N., A. Moscrop, and C. Carlson. 2001. Elements for the Development of a Marine Mammal Action Plan for the Wider Caribbean. A Review of Marine Mammal Distribution. First Meeting of the Contracting Parties (COP) to the Protocol Concerning Specially Protected Areas and Wildlife (SPAW) in the Wider Caribbean Region. Havan, Cuba, 24-25 September 2021, UNEP.

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.

Webster, F.J., B.S. Wise, W.J. Fletcher, and H. Kemps. 2018. Risk assessment of the potential impacts of seismic air gun surveys on marine finfish and invertebrates in Western Australia. Fisheries Research Report No. 288 Department of Primary Industries and Regional Development, Western Australia. 42 p.

Weidner, D.M. 2001. World Swordfish Fisheries: An Analysis of Swordfish Fisheries, Market Trends, and Trade Patterns Past-Present-Future, Volume IV. Latin America, Part B. Caribbean, Section 2. Cayman Islands and Cuba.

Weilgart, L. 2017a. Din of the deep: noise in the ocean and its impacts on cetaceans. p. 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.

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.

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. 2018. Bottlenose dolphin, *Tursiops truncatus*, common bottlenose dolphin. p. 118-124 In: B. Würsig, J.G.M. Thewissen, and K.M. Kovacs (eds.), Encyclopedia of Marine Mammals, 3rd ed. Academic Press/Elsevier, San Diego, CA. 1157 p.

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.

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.

Wenzel, F.W., J. Allen, S. Berrow, C.J. Hazevoet, B. Jann, R. E. Seton, L. Steiner, P. Stevick, P. López Suárez, and P. Whooley. 2009. Current knowledge on the distribution and relative abundance of humpback whales (*Megaptera novaeangliae*) off the Cape Verde Islands, eastern North Atlantic. **Aquatic Mamm.** 35(4):502-510.

Whaley, A.R., E.C.M. Parsons, R. Sellares, and I.B. de Calventini. 2006. Dolphin ecology and behaviour in the southeastern waters of the Dominican Republic: preliminary observations. IWC Paper SC58/SM12 presented to the Scientific Committee at the 58th Meeting of the International Whaling Commission, St Kitts.

Whitehead, H. 2018. Sperm whale *Physeter macrocephalus*. p. 919-925 *In:* B. Würsig, J.G.M. Thewissen, and K.M. Kovacs (eds.), Encyclopedia of Marine Mammals, 3rd Edition. Academic Press/Elsevier, San Diego, CA. 1157 p.

Whitehead, H. and M.J. Moore. 1992. Distribution and movements of West Indian humpback whales in winter. **Can. J. Zool.** 60:2203-2211.

Whitt, A.D., T.A. Jefferson, M. Blanco, D. Fertl, and D. Rees. 2011. A review of marine mammal records of Cuba. **Latin Am. J. Aquatic Mamm.** 9(2):65-122.

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, R., E. Ashe, L. Yruretagoyena, N. Mastick, M. Siple, J. Wood, R. Joy, R. Langrock, S. Mews, and E. Finne. Reducing vessel noise increases foraging in endangered killer whales. **Mar. Poll. Bull.** 173:112976.

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.

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.

Wong, M. 2020. Popular Caribbean spots for whale watching. Loop. Accessed December 2021 at https://caribbean.loopnews.com/content/popular-caribbean-spots-whale-watching.

Wright, A., and L.A. Kyhn. 2014. Practical management of cumulative anthropogenic impacts with working marine examples. **Conserv. Biol.** 29(2): 333-340.

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.

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. 2017. Marine mammals of the Gulf of Mexico. Chapter 13 *In:* C.H. Ward (ed.) Habitats and Biota of the Gulf of Mexico: Before the Deepwater Horizon Oil Spill. Volume 2: Fish Resources, Fisheries, Sea Turtles, Avian Resources, Marine Mammals, Diseases and Mortalities. Springer Nature, New York.

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. **Aquatic Mamm.** 24(1):41-50.

Würsig, B., T.A. Jefferson, and D.J. Schmidly. 2000. The marine mammals of the Gulf of Mexico. Texas A&M University Press, College Station, TX. 232 p.

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. 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.

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.

Yu, Z.H., H.S. Yang, B.Z. Liu, Q. Xu, K. Xing, and 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.

Zerbini, A.N., A. Andriolo, M.-P. Heide-Jørgensen, S.C. Moreira, J.L. Pizzorno, Y.G. Maia, G.R. VanBlaricom, and D.P. DeMaster. 2011. Migration and summer destinations of humpback whale (*Megaptera novaeangliae*) in the western South Atlantic Ocean. **J. Cetac. Res. Manage.** (Spec. Iss.) 3:113-118.

Žydelis, R., C. Small, and G. French. 2013. The incidental catch of seabirds in gillnet fisheries: A global review. **Biol. Conserv.** 162:76-88.

# LIST OF APPENDICES

# 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 for the high-energy surveys and safety zones (160 dB re 1µPa$_{\text{rms}}$) for Level B takes for the high- and low-energy surveys. 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, two 45/105 in$^3$ GI airguns, and for a single 1900LL 40-in$^3$ airgun, which would be used during power downs. Models for the 36-airgun array and 40-in$^3$ airgun used a 12-m tow depth, whereas the model for the two GI airguns used a 3-m tow depth. 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).

Typically, for deep and intermediate-water cases, the field measurements cannot be used readily to derive mitigation radii, as at those GoM 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 (Costa and Williams 1999). 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 and intermediate-water depths, 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. In shallow water (<100 m), the depth of the calibration hydrophone (18 m) used during the GoM calibration survey was appropriate to sample the maximum sound level in the water column, and the field measurements reported in Table 1 of Tolstoy et al. (2009) for the 36-airgun array at a tow depth of 6 m can be used to derive mitigation radii.

The proposed high-energy surveys would acquire data with the 36-airgun array at a maximum tow depth of 12 m, and the USGS low-energy surveys would use two GI airguns at a 3-m tow depth. 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 array (Fig. A-1), the 2 GI airguns (Fig. A-2), and for the 40-in$^3$ airgun (Fig. A-3). The radii for intermediate water depths (100–1000 m) are derived from the deep-water ones by applying a correction factor (multiplication) of 1.5, such that observed levels at very near offsets fall below the corrected mitigation curve (Fig. 16 in Appendix H of the PEIS. No effort would occur in shallow water during the proposed surveys.

Table A-1 shows the distances at which the 160-dB and 175-dB re 1µPa$_{rms}$ sound levels are expected to be received for the 36-airgun array and the single (mitigation) airgun. The 160-dB level is the behavioral disturbance criteria (Level B) that is used by NMFS to estimate anticipated takes for marine mammal. The 175-dB level is used by NMFS, based on data from the DoN (2017), to determine behavioral disturbance for sea turtles. 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 levels[3] 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 technical guidance for assessing the effects of anthropogenic sound on marine mammal hearing (NMFS 2016, 2018). The 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). The largest distance of the dual criteria ($SEL_{cum}$ or Peak $SPL_{flat}$) was used to calculate takes and Level A threshold distances. The dual criteria for sea turtles (DoN 2017) were also used here. The new NMFS guidance did not alter the current threshold, 160 dB re 1µPa$_{rms}$, for Level B harassment (behavior). It should be recognized that there are a number of limitations and uncertainties associated with these injury criteria (Southall et al. 2007). Lucke et al. (2020) caution that some current thresholds may not be able to accurately predict hearing impairment and other injury to marine mammals due to noise. Tougaard et al. (2022) indicate that there is empirical evidence to support the thresholds for very-high frequency cetaceans and pinnipeds in water, but caution that above 10 kHz for porpoise and outside of 3–16 kHz for seals, there are differences between the TTS thresholds and empirical data.

---

[3] 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).

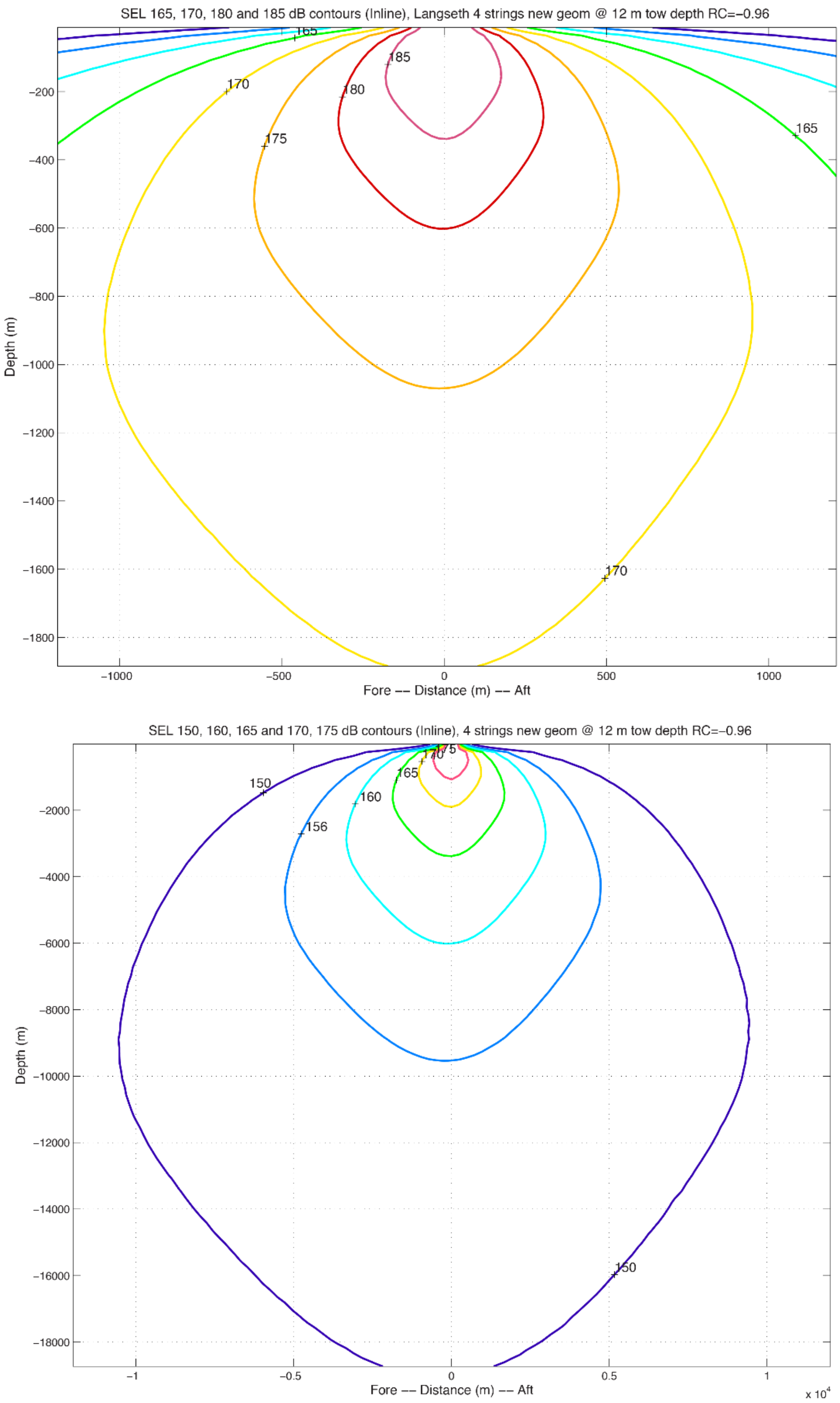


FIGURE A-1. Modeled deep-water received sound exposure levels (SELs) from the 36-airgun array at a 12-m tow depth planned for use during the proposed surveys off Puerto Rico. Received rms levels (SPLs) are expected to be ~10 dB higher. For example, the radius to the 150-dB SEL isopleth is a proxy for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

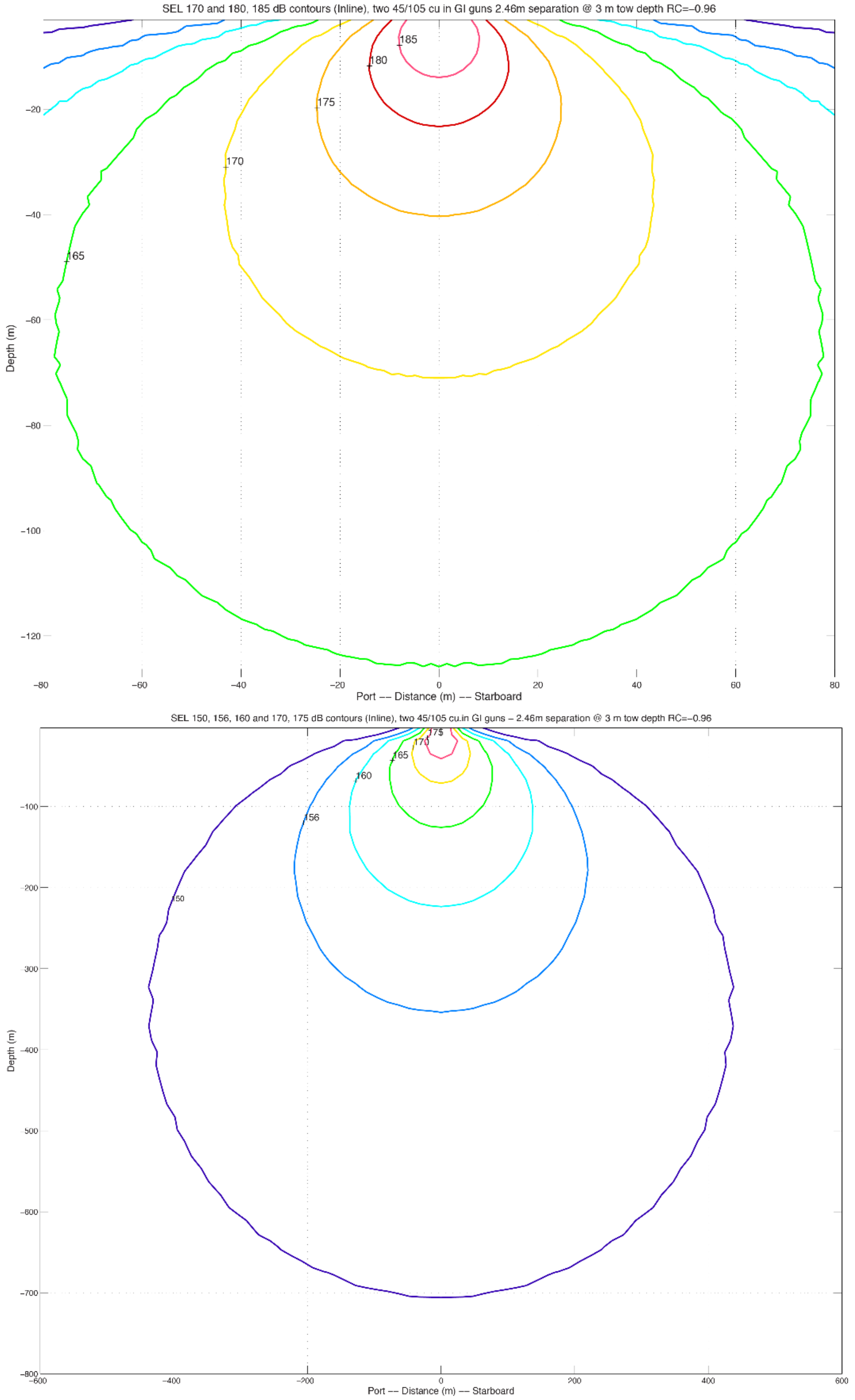


FIGURE A-2. Modeled deep-water received sound exposure levels (SELs) from the two 45/100 in$^3$ GI airguns at a 3-m tow depth planned for use during the proposed USGS surveys off southern Puerto Rico. Received rms levels (SPLs) are expected to be ~10 dB higher. For example, the radius to the 150-dB SEL isopleth is a proxy for the 160-dB rms isopleth. The upper plot is a zoomed-in version of the lower plot.

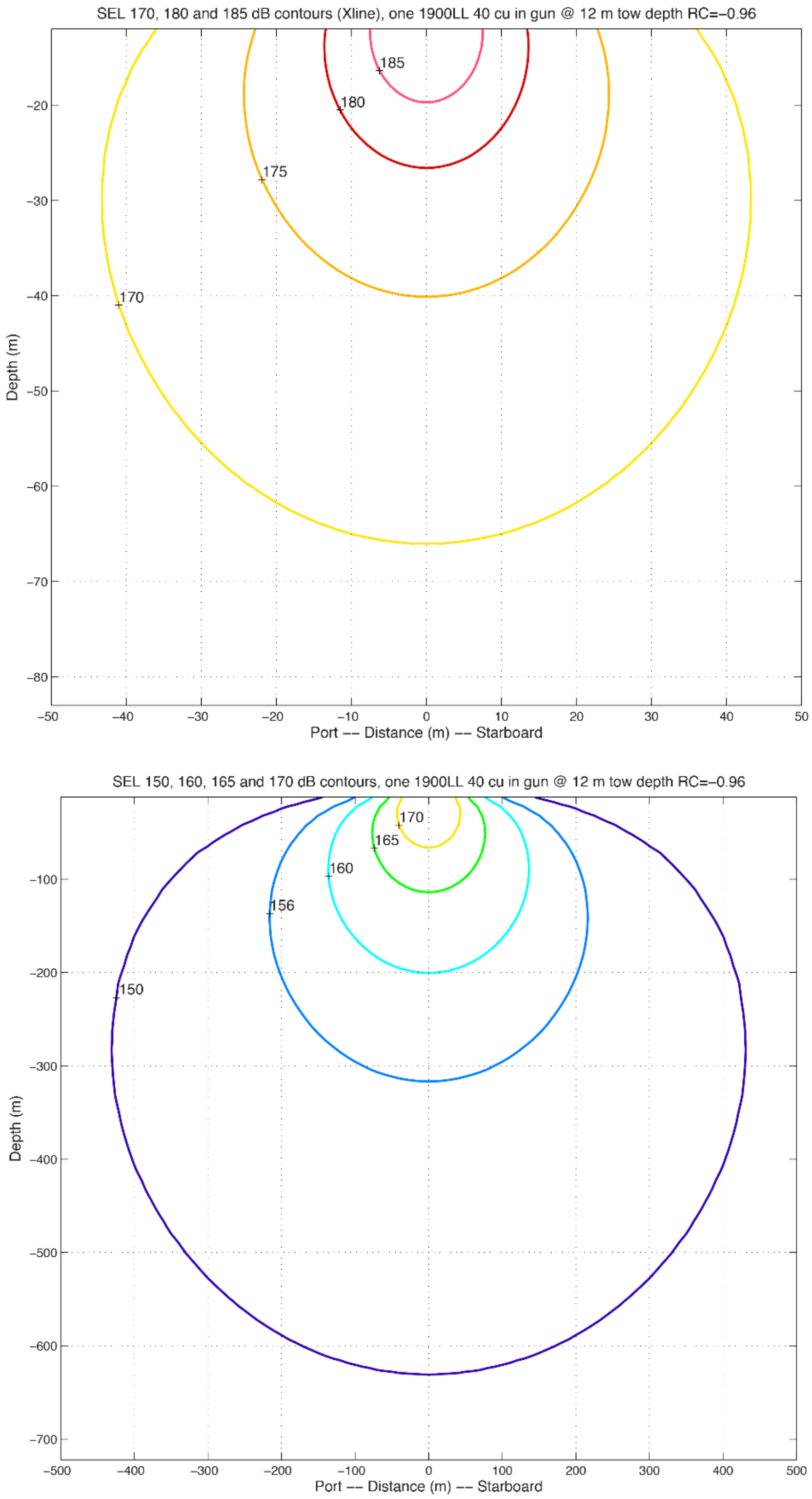


FIGURE A-3. Modeled deep-water received SELs from a single 40-in$^3$ airgun towed at a 12-m depth, which is planned for use during power downs during the proposed high-energy surveys off Puerto Rico. Received rms levels (SPLs) are expected to be ~10 dB higher. For example, the radius to the 150-dB SEL 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. Level B. Predicted distances to which sound levels ≥160-dB re 1 μPa$_{rms}$ could be received during the proposed surveys off Puerto Rico. The 160-dB criterion applies to all hearing groups of marine mammals, and the 175-dB criterion applies to sea turtles.

| Source and Volume | Tow Depth (m) | Water Depth (m) | Predicted distances (in m) to the 160-dB Received Sound Level | Predicted distances (in m) to the 175-dB Received Sound Level |
|---|---|---|---|---|
| Single Bolt airgun, 40 in$^3$ | 12 | >1000 m | 431[1] | 77[1,3] |
| | | 100–1000 m | 647[2] | 116[2] |
| 4 strings, 36 airguns, 6600 in$^3$ | 12 | >1000 m | 6,733[1] | 1,864[1] |
| | | 100–1000 m | 10,100[2] | 2,796[2] |
| Two 45/105 in$^3$ GI airguns | 3 | >1000 m | 438[1] | 78[1,3] |
| | | 100–1000 m | 657[2] | 117[2] |

[1] Distance is based on L-DEO model results. [2] Distance is based on L-DEO model results with a 1.5 × correction factor between deep and intermediate water depths. [3] An EZ of 150 m would be used as the shut-down distance for sea turtles and ESA listed seabirds in all water depths.

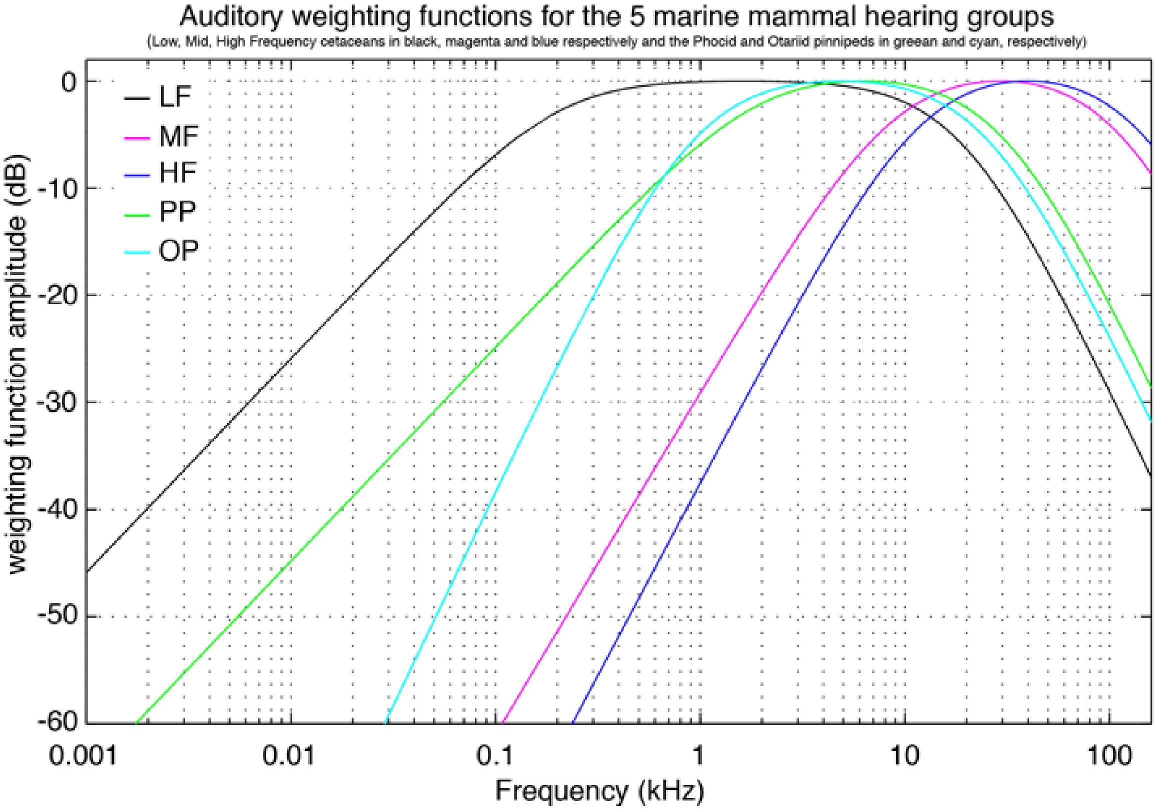


FIGURE A-4. Auditory weighting functions for five marine mammal hearing groups from the NMFS Technical Guidance Spreadsheet.

Southall et al. (2019) provided updated scientific recommendations regarding noise exposure criteria which are similar to those presented by NMFS (2016, 2018), but include all marine mammals (including sirenians), and a re-classification of hearing groups

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 (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 23.1 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 and the single 40-in$^3$ mitigation airgun.

For the LF cetaceans during operations with the 36-airgun array, 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 of -12.91 dB assuming a propagation of $20\log_{10}$(Radial distance) (Table A-2).

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).

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

| **$\mathrm{SEL}_{cum}$ Threshold** | **183** | **185** | **155** | **185** | **203** | **204*** |
|---|---|---|---|---|---|---|
| **Radial Distance (m) (no weighting** | 315.5691 | 246.4678 | 8033.2 | 246.4678 | 28.4413 | 25.1030 |
| **Modified Farfield SEL** | 232.9819 | 232.8352 | 233.0978 | 232.8352 | 232.0790 | 231.9945 |
| **Radial Distance (m) (with weighting function)** | 71.3752 | N.A. | N.A. | N.A. | N.A. | N.A. |
| **Adjustment (dB)** | -12.91 | N.A. | N.A. | N.A. | N.A. | N.A. |

* Sea turtles. N.A. means not applicable or not available.

For the 36-airgun array, the results for single shot SEL source level modeling are shown in Table A-2. The weighting function calculations, thresholds for $\mathrm{SEL}_{cum}$, and the distances to the PTS thresholds for the 36-airgun array are shown in Table A-3. Figure A-5 shows the impact of weighting functions by hearing group. Figures A-5–A-7 show the modeled received sound levels for single shot SEL without applying auditory weighting functions for various hearing groups. Figure A-8 shows the modeled received sound levels for single shot SEL with weighting for LF cetaceans.

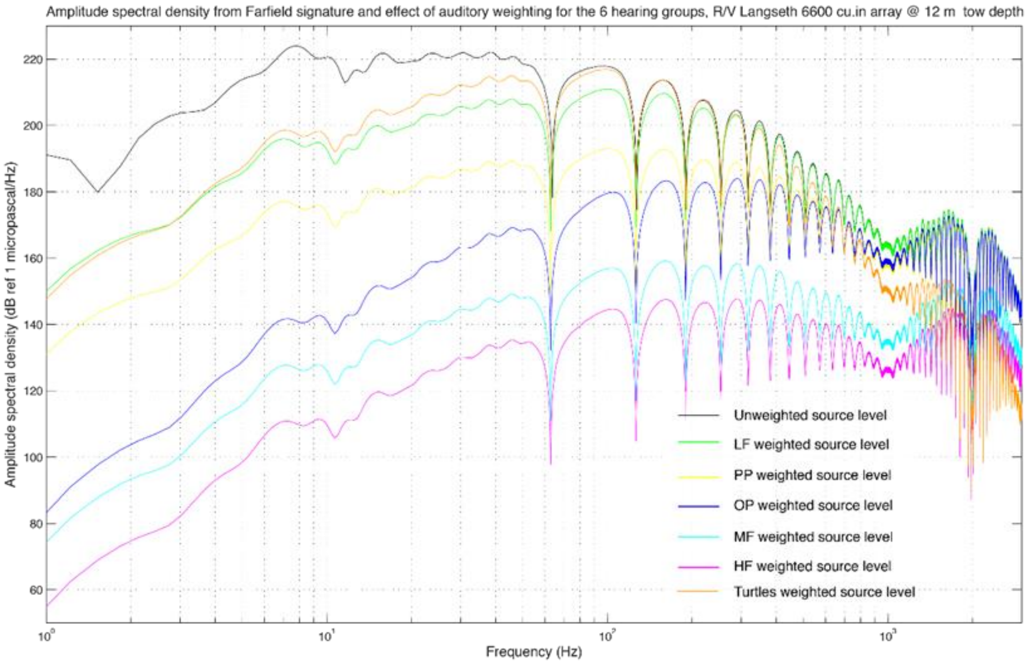
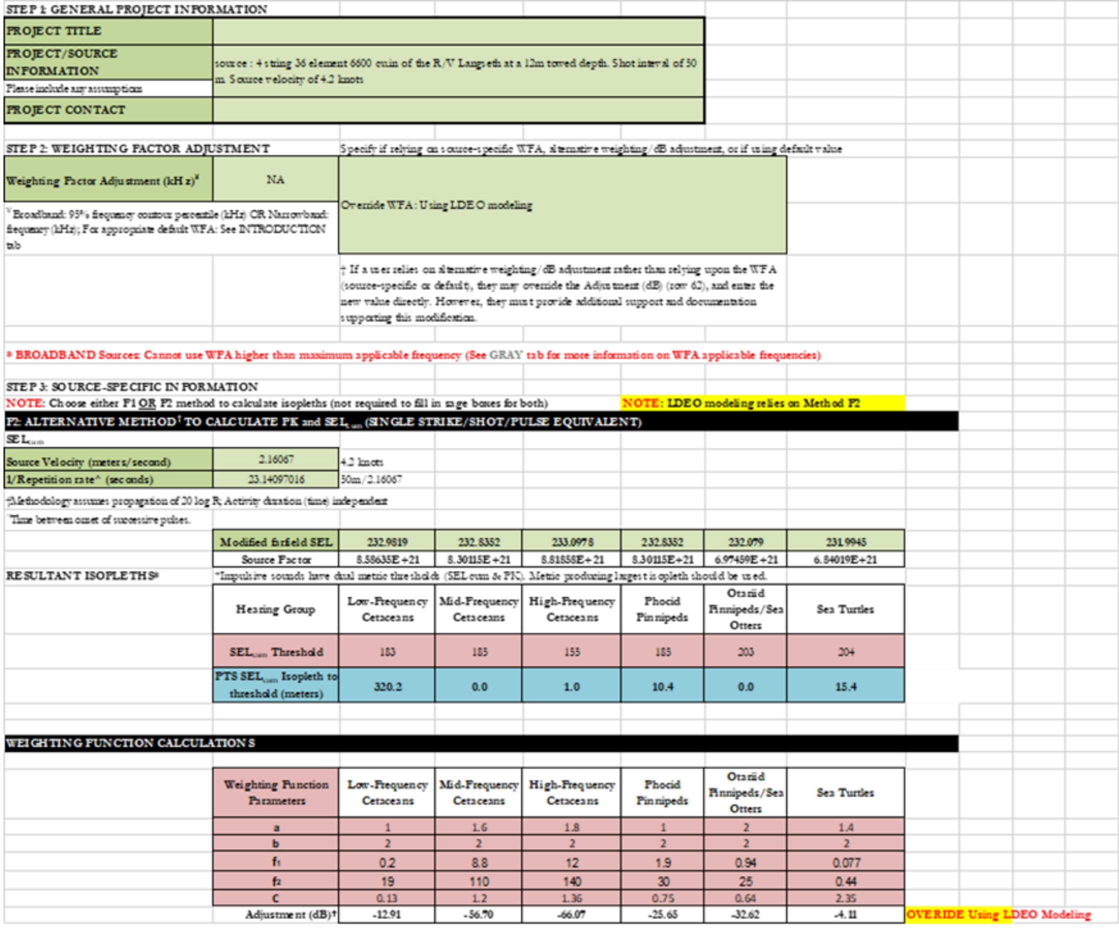


FIGURE A-5. Modeled amplitude spectral density of the 36-airgun array farfield signature. Amplitude spectral density before (black) and after (colors) applying the auditory weighting functions for LF, MF, and HF cetaceans, Phocid Pinnipeds (PP), and Otariid Pinnipeds (OP). Modeled spectral levels are 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 | |
| PROJECT/SOURCE INFORMATION<br>Please include any assumptions | source : 4 string 36 element 6600 cuin of the R/V Langseth at a 12m towed depth. Shot interval of 50 m. Source velocity of 4.2 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.

* 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) | 23.14097016 | 50m/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 | 231.9945 |
| Source Factor | 8.58635E+21 | 8.30115E+21 | 8.81858E+21 | 8.30115E+21 | 6.97459E+21 | 6.84019E+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/Sea Otters | Sea Turtles |
|---|---|---|---|---|---|---|
| $SEL_{cum}$ Threshold | 183 | 185 | 155 | 185 | 203 | 204 |
| PTS $SEL_{cum}$ Isopleth to threshold (meters) | 320.2 | 0.0 | 1.0 | 10.4 | 0.0 | 15.4 |

WEIGHTING FUNCTION CALCULATIONS

| Weighting Function Parameters | Low-Frequency Cetaceans | Mid-Frequency Cetaceans | High-Frequency Cetaceans | Phocid Pinnipeds | Otariid Pinnipeds/Sea Otters | Sea Turtles |
|---|---|---|---|---|---|---|
| a | 1 | 1.6 | 1.8 | 1 | 2 | 1.4 |
| b | 2 | 2 | 2 | 2 | 2 | 2 |
| $f_1$ | 0.2 | 8.8 | 12 | 1.9 | 0.94 | 0.077 |
| $f_2$ | 19 | 110 | 140 | 30 | 25 | 0.44 |
| C | 0.13 | 1.2 | 1.36 | 0.75 | 0.64 | 2.35 |
| Adjustment (dB)† | -12.91 | -56.70 | -66.07 | -25.65 | -32.62 | -4.11 |

OVERIDE 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 $20*\log_{10}$ (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).

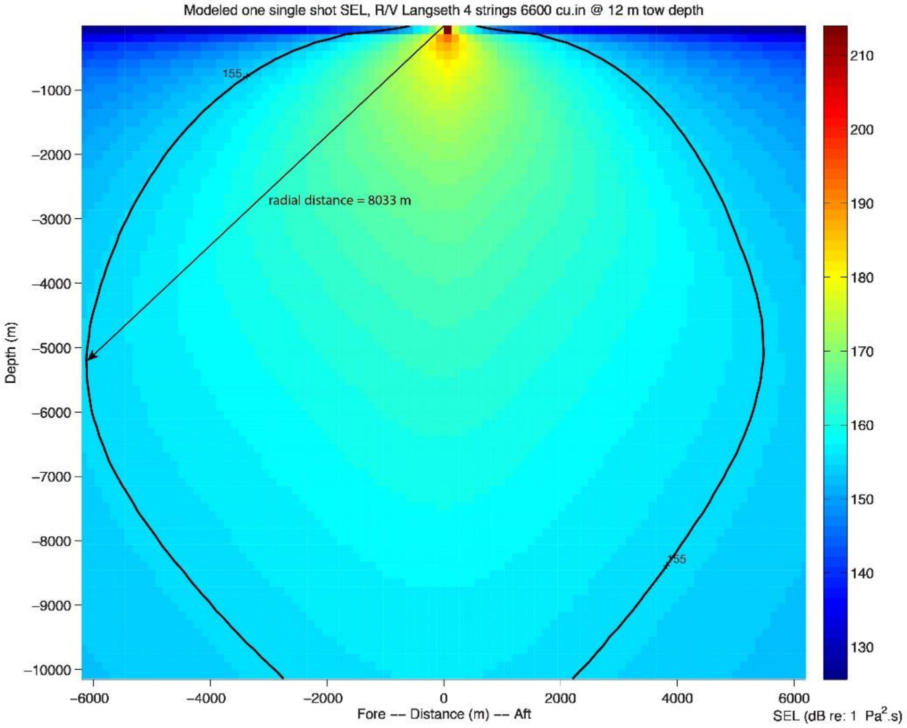


FIGURE A-6. Modeled received sound levels (SELs) in deep water from the 36-airgun array. The plot provides the radial distance from the geometrical center of the source array to the 155-dB SEL isopleth (8033 m). Radial distance allows us to determine the modified farfield SEL using a propagation of $20\log_{10}$(radial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

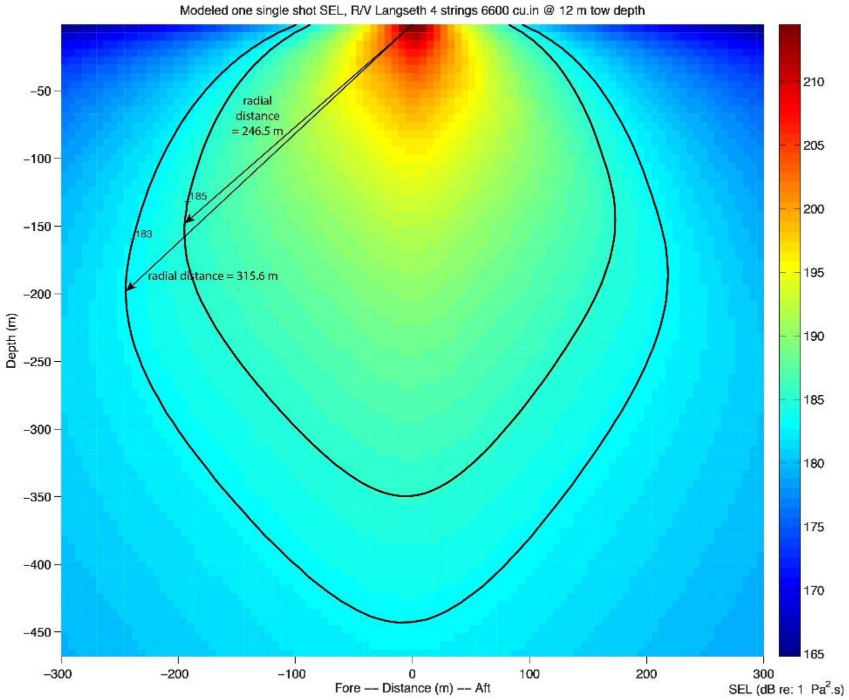


FIGURE A-7. Modeled received sound levels (SELs) in deep water from the 36-airgun array. The plot provides the radial distance from the geometrical center of the source array to the 183–185-dB SEL isopleths (315.6 and 246.5 m, respectively).

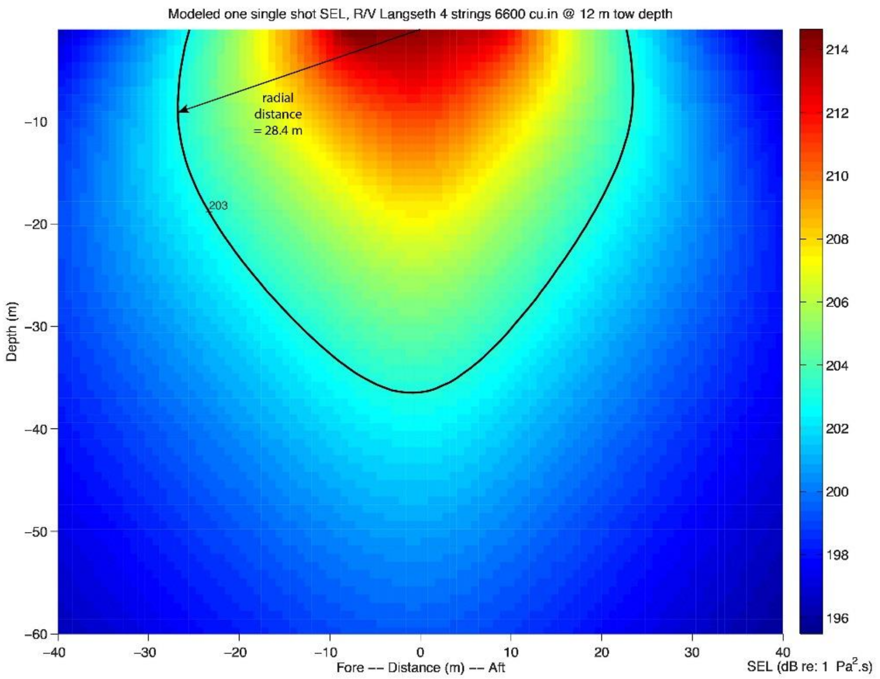


FIGURE A-8. Modeled received sound levels (SELs) in deep water from the 36-airgun array. The plot provides the radial distance from the geometrical center of the source array to the 203-dB SEL isopleth (28.4 m).

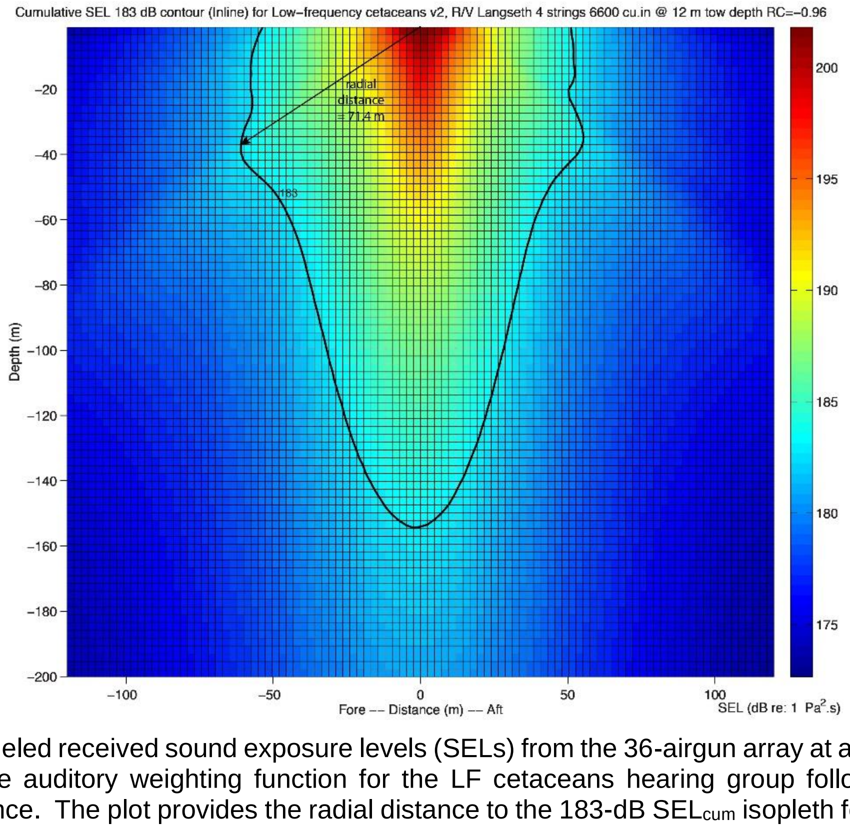


FIGURE A-9. Modeled received sound exposure levels (SELs) from the 36-airgun array at a 12-m tow depth, after applying the auditory weighting function for the LF cetaceans hearing group following the NMFS Technical Guidance. The plot provides the radial distance to the 183-dB $SEL_{cum}$ isopleth for 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.

The thresholds for Peak $\text{SPL}_{\text{flat}}$ 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 $\text{SPL}_{\text{flat}}$ thresholds, for a single shot. A summary of the Level A threshold distances are shown in Table A-5.

TABLE A-4. NMFS Level A acoustic thresholds (Peak $\text{SPL}_{\text{flat}}$) for impulsive sources for marine mammals and sea turtles and predicted distances to Level A thresholds for various hearing groups that could be received from the 36-airgun array during the proposed surveys off Puerto Rico.

| Hearing Group | Low-Frequency Cetaceans | Mid-Frequency Cetaceans | High-Frequency Cetaceans | Phocid Pinnipeds | Otariid Pinnipeds/ Sea Turtles |
|---|---|---|---|---|---|
| **Peak Threshold** | **219** | **230** | **202** | **218** | **232** |
| **Radial Distance to Threshold (m)** | 45.00 | 13.57 | 364.67 | 51.59 | 10.62 |
| **Modified Farfield Peak SPL** | 252.06 | 252.65 | 253.24 | 252.25 | 252.52 |
| **PTS Peak Isopleth (Radius) to Threshold (m)** | 38.9 | 13.6 | 268.3 | 43.7 | 10.6 |

N.A. means not applicable or not available.

TABLE A-5. Level A threshold distances for different marine mammal hearing groups and sea turtles for the 36-airgun array. Following the guidance by NMFS (2016, 2018), the largest distance (in bold) of the dual criteria ($\text{SEL}_{\text{cum}}$ or Peak $\text{SPL}_{\text{flat}}$) was used to calculate Level A takes and threshold distances.

| | **Level A Threshold Distances (m) for Various Hearing Groups** | | | | | |
|---|---|---|---|---|---|---|
| | **Low-Frequency Cetaceans** | **Mid-Frequency Cetaceans** | **High-Frequency Cetaceans** | **Phocid Pinnipeds** | **Otariid Pinnipeds** | **Sea Turtles** |
| **PTS $\text{SEL}_{\text{cum}}$** | **320.2** | 0 | 1.0 | 10.4 | 0 | **15.4** |
| **PTS Peak** | 38.9 | **13.6** | **268.3** | **43.7** | **10.6** | 10.6 |

[1] Using the 50-m shot interval provides more conservative distances than the 400-m shot interval.

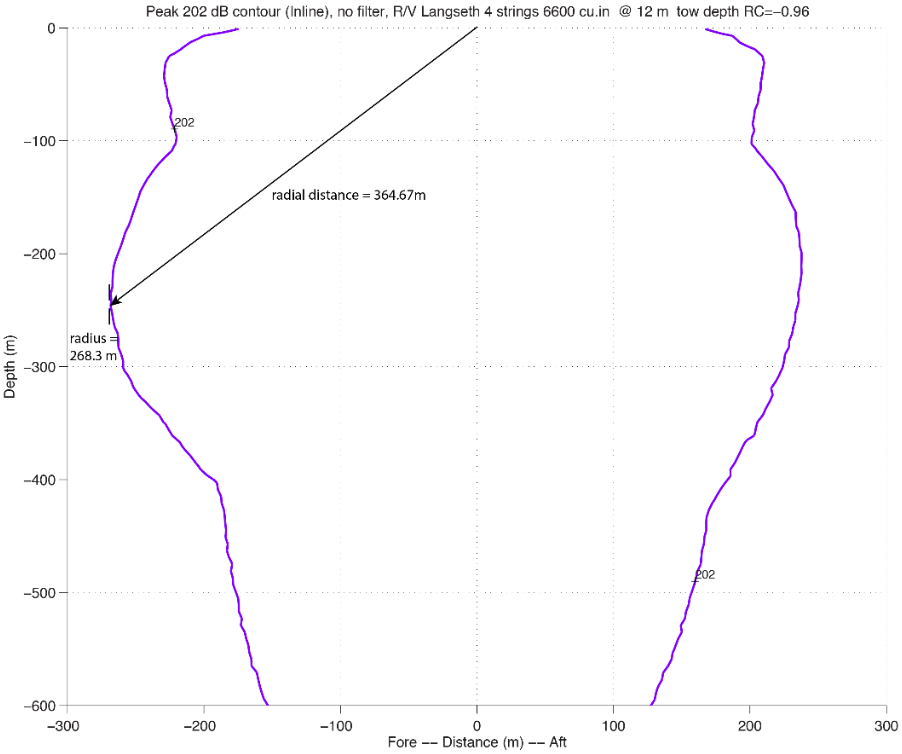


FIGURE A-10. Modeled deep-water received Peak SPL from the 36-airgun array at a 12-m tow depth. The plot provides the distance to the 202-dB Peak isopleth.

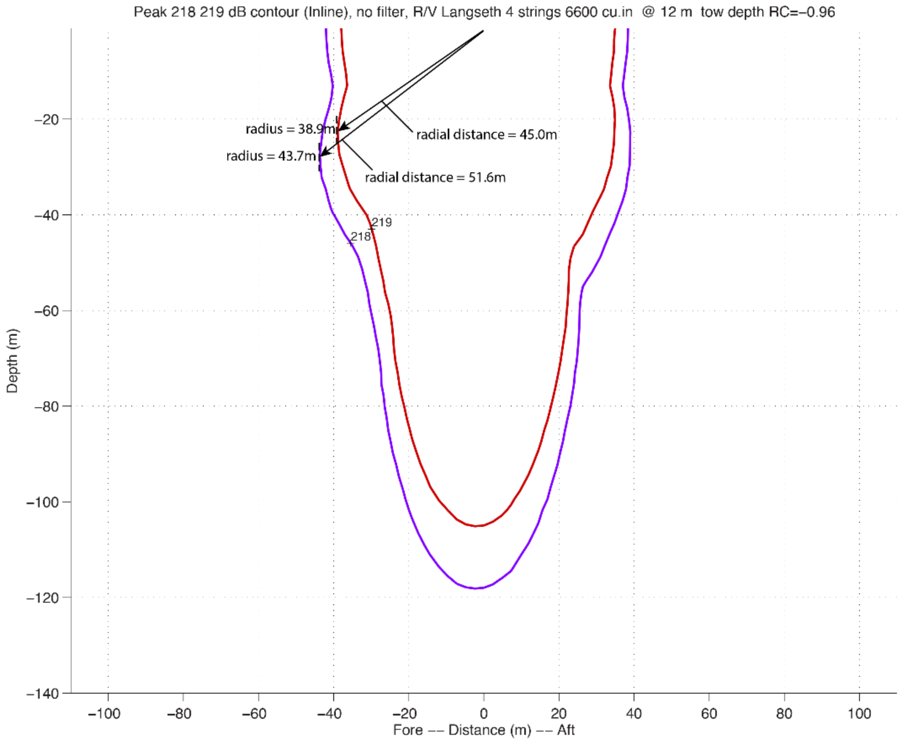


FIGURE A-11. Modeled deep-water received Peak SPL from the 36-airgun array at a 12-m tow depth. The plot provides the distances to the 218- and 219-dB Peak isopleths.

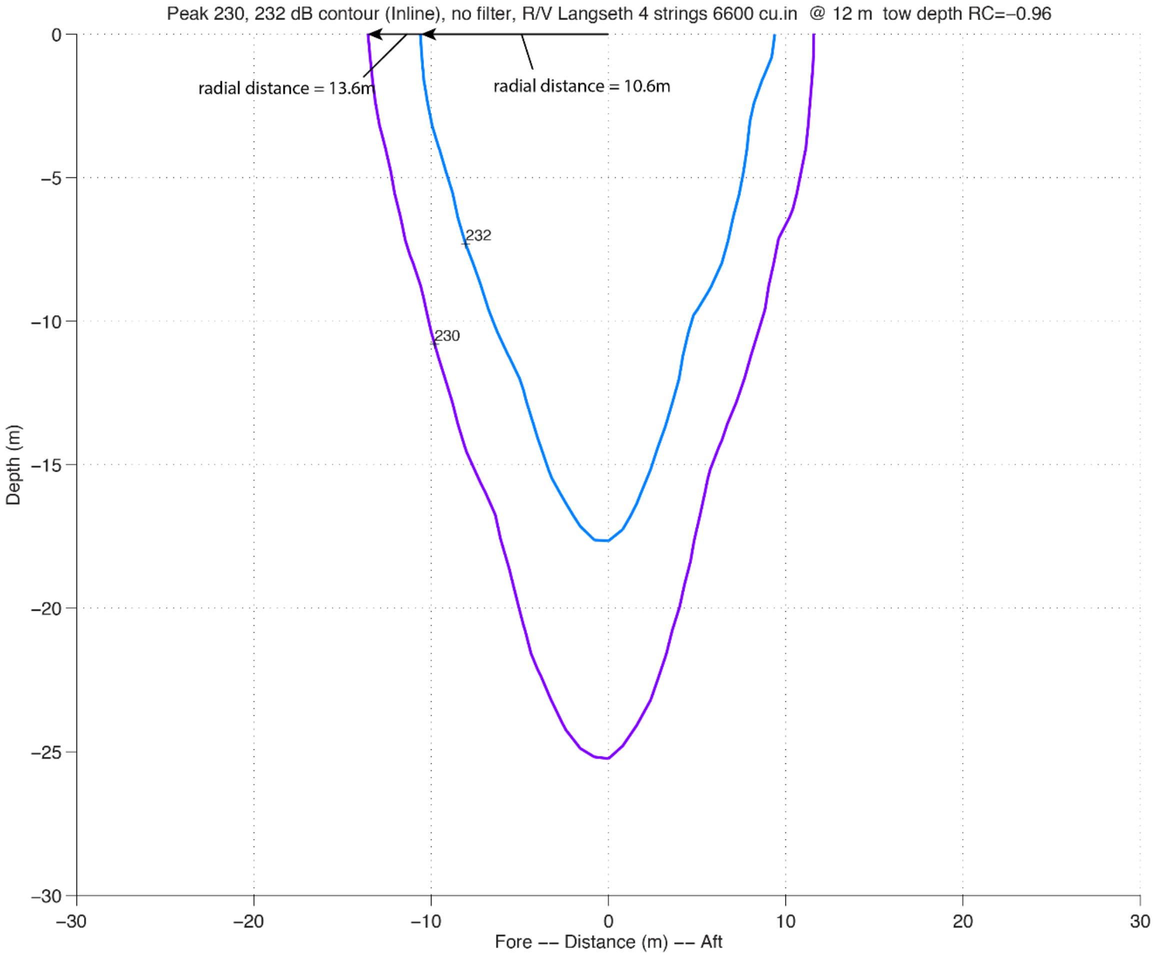


FIGURE A-12. Modeled deep-water received Peak SPL from the 36-airgun array at a 12-m tow depth. The plot provides the distances to the 230- and 232-dB Peak isopleths.

For the single 40 in$^3$ mitigation airgun, the results for single shot SEL source level modeling are shown in Table A-6. The weighting function calculations, thresholds for SEL$_{cum}$, and the distances to the PTS thresholds for the 40 in$^3$ airgun are shown in Table A-7. Figure A-13 shows the impact of weighting functions by hearing group for the single mitigation airgun. 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 40 in$^3$ airgun, as well as the distances to the PTS thresholds, are shown in Table A-8. Figures A-17–A-18 show the modeled received sound levels to the Peak SPL$_{flat}$ thresholds, for a single shot.

TABLE A-6. Results for single shot SEL source level modeling for the 40 in$^3$ 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 $\text{SEL}_{\text{cum}}$ threshold is the largest. A propagation of 20 $\log_{10}$ (Radial distance) is used to estimate the modified farfield SEL.

| **$\text{SEL}_{\text{cum}}$ 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.

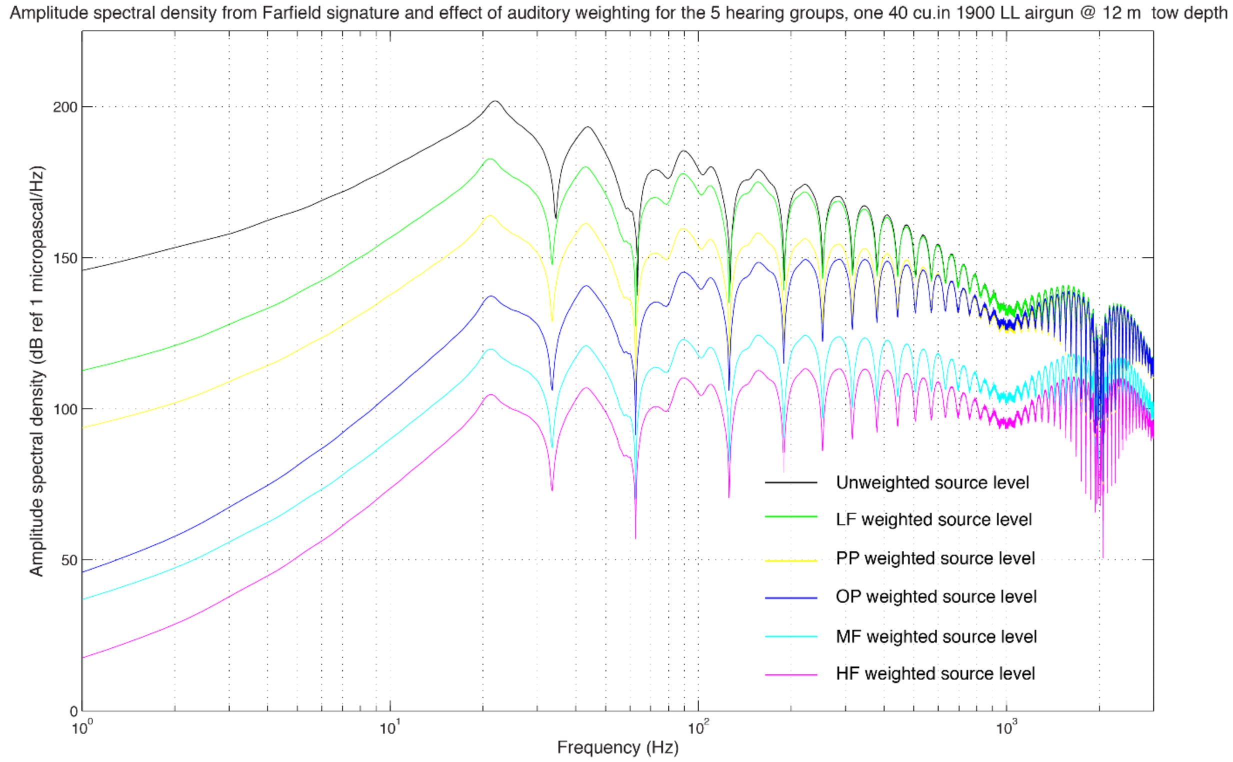
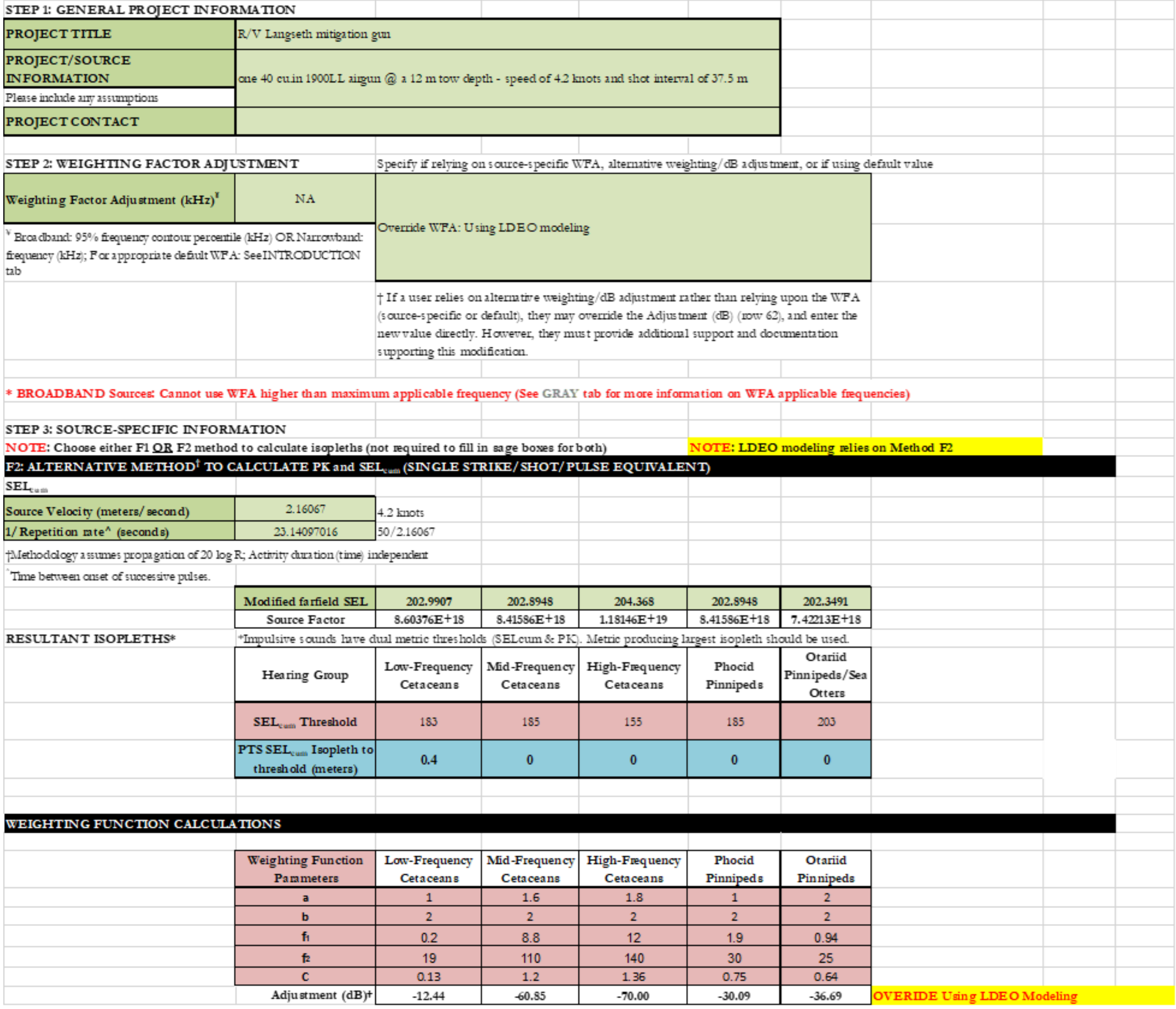


FIGURE A-13. Modeled amplitude spectral density of the 40-in$^3$ airgun farfield signature. Amplitude spectral density before (black) and after (colors) applying the auditory weighting functions for LF, MF, and HF cetaceans, Phocid Pinnipeds (PP), and Otariid Pinnipeds (OP). Modeled spectral levels are 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-7. Results for single shot SEL source level modeling for the single 40-in$^3$ 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 |
| **PROJECT/SOURCE INFORMATION**<br>Please include any assumptions | one 40 cu.in 1900LL airgun @ a 12 m tow depth - speed of 4.2 knots and shot interval of 37.5 m |
| **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)** | 2.16067 | 4.2 knots |
| **1/Repetition rate^ (seconds)** | 23.14097016 | 50/2.16067 |

†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** | **8.60376E+18** | **8.41586E+18** | **1.18146E+19** | **8.41586E+18** | **7.42213E+18** |

**RESULTANT ISOPLETHS***

*Impulsive sounds have dual metric thresholds (SELcum & PK). Metric producing largest isopleth should be used.

| **Hearing Group** | **Low-Frequency Cetaceans** | **Mid-Frequency Cetaceans** | **High-Frequency Cetaceans** | **Phocid Pinnipeds** | **Otariid Pinnipeds/Sea Otters** |
|---|---|---|---|---|---|
| **SEL$_{cum}$ Threshold** | 183 | 185 | 155 | 185 | 203 |
| **PTS SEL$_{cum}$ Isopleth to threshold (meters)** | 0.4 | 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** | **OVERIDE 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*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-13).

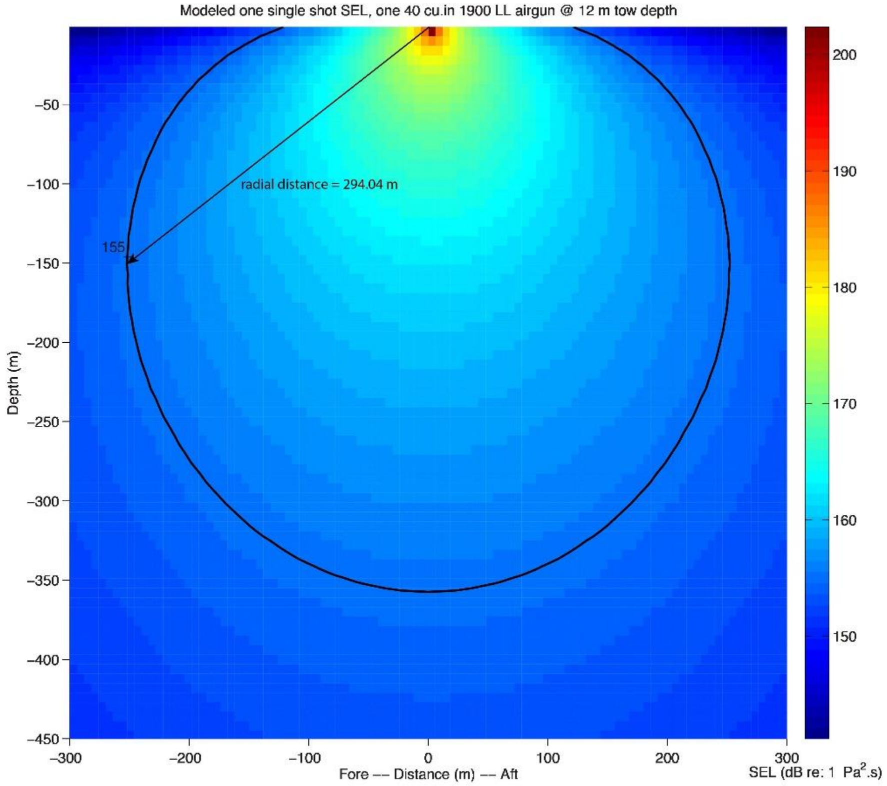


FIGURE A-14. Modeled received sound levels (SELs) in deep water from one 40-in$^3$ airgun at a 12-m tow depth. The plot provides the distance from the geometrical center of the source array to the 155-dB SEL isopleth (294.04 m).

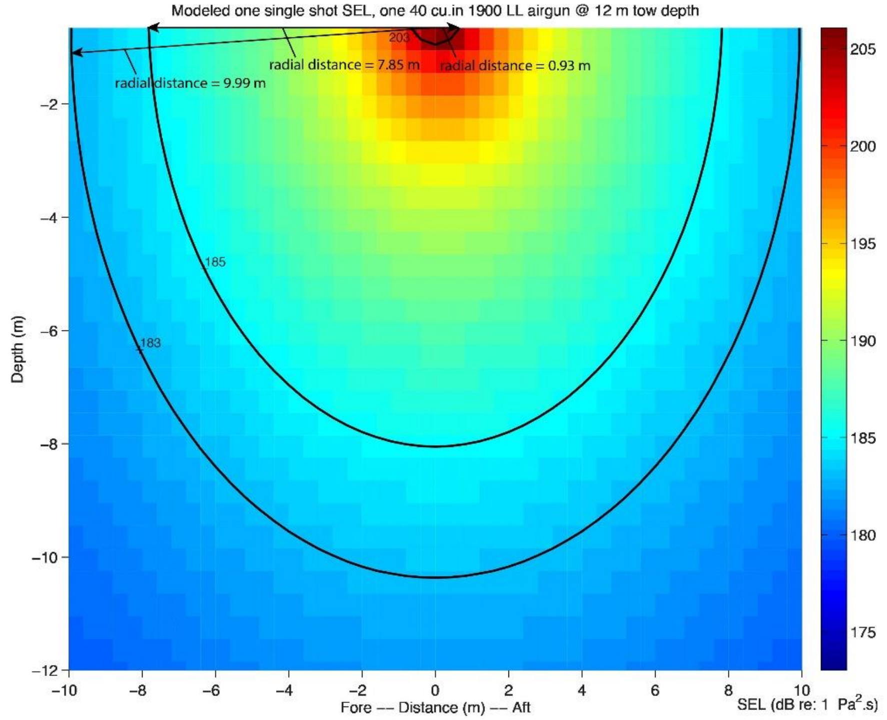


FIGURE A-15. Modeled received sound levels (SELs) in deep water from one 40-in$^3$ airgun at a 12-m tow depth. The plot provides the distance from the geometrical center of the source array to the 183–185 dB and 203 dB SEL isopleths.

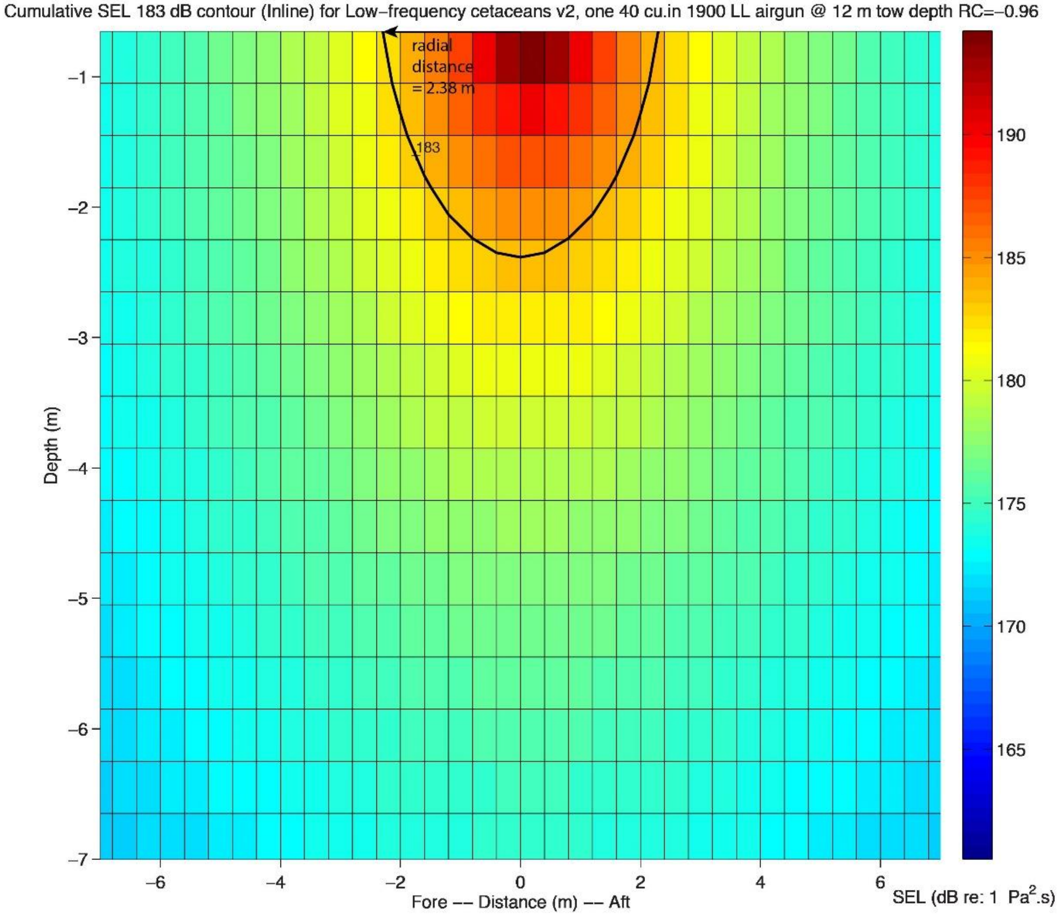


FIGURE A-16. Modeled received sound exposure levels (SELs) from one 40-in$^3$ mitigation at a 12-m tow depth, after applying the auditory weighting function for the LF cetaceans hearing group following the NMFS Technical Guidance. The plot provides the radial distance to the 183-dB SEL$_{cum}$ isopleth for one shot. The difference in radial distances between Fig. A-15 and this figure allows us to estimate the adjustment in dB.

TABLE A-8. NMFS Level A acoustic thresholds (Peak SPL$_{flat}$) for impulsive sources for marine mammals and sea turtles and predicted distances to Level A thresholds for various marine mammal hearing groups that could be received from the 40-in$^3$ airgun during the proposed seismic surveys off Puerto Rico.

| Hearing Group | Low-Frequency Cetaceans | Mid-Frequency Cetaceans | High-Frequency Cetaceans | Phocid Pinnipeds | Otariid Pinnipeds/ Sea Turtles |
|---|---|---|---|---|---|
| **Peak Threshold** | **219** | **230** | **202** | **218** | **232** |
| **Radial Distance to Threshold (m)** | 1.76 | N.A. | 12.47 | 1.98 | N.A. |
| **Modified Farfield Peak** | 223.93 | 224.09 | 223.92 | 223.95 | 223.95 |
| **PTS Peak Isopleth (Radius) to Threshold (m)** | 1.76 | N.A. | 12.5 | 1.98 | N.A. |

N.A. means not applicable or not available.

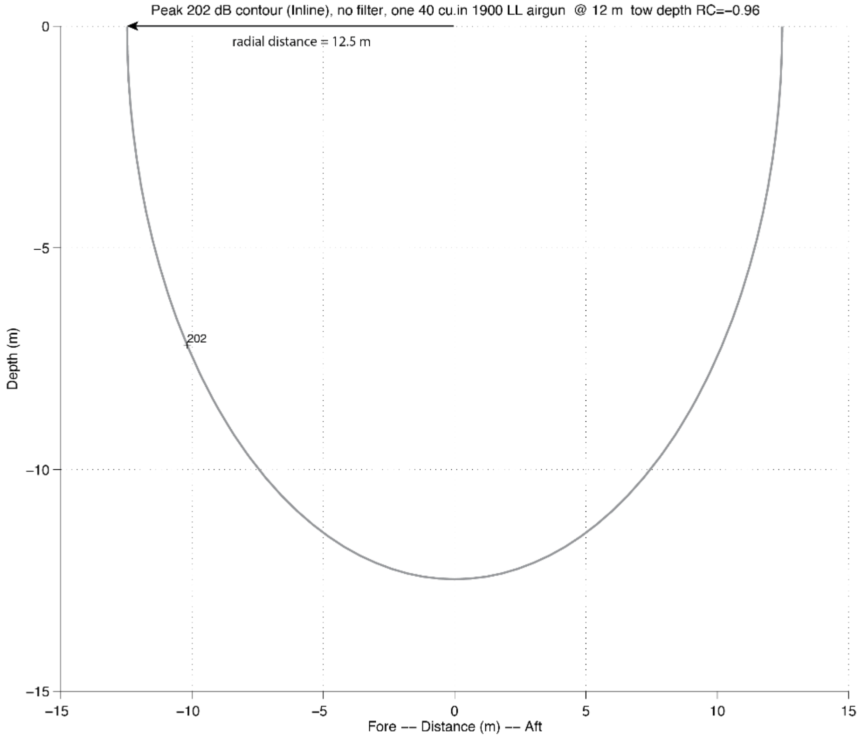


FIGURE A-17. Modeled deep-water received Peak SPL from one 40 in$^3$ airgun at a 12-m tow depth. The plot provides the radial distance from the source geometrical center to the 202-dB Peak isopleth.

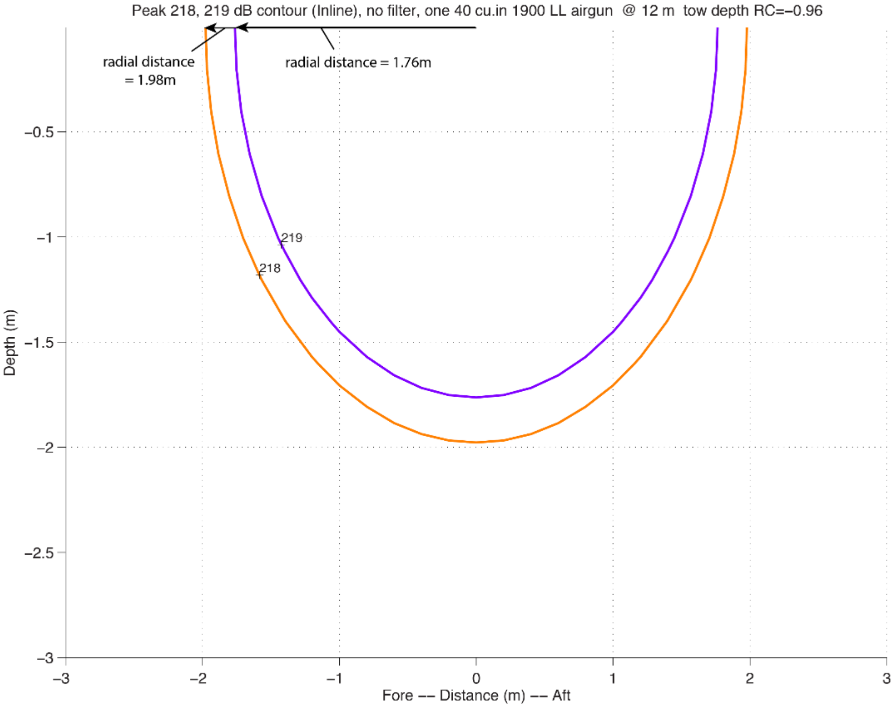


FIGURE A-18. Modeled deep-water received Peak SPL from one 40 in$^3$ airgun at a 12-m tow depth. The plot provides the radial distances from the source geometrical center to the 218 and 219-dB Peak isopleths.

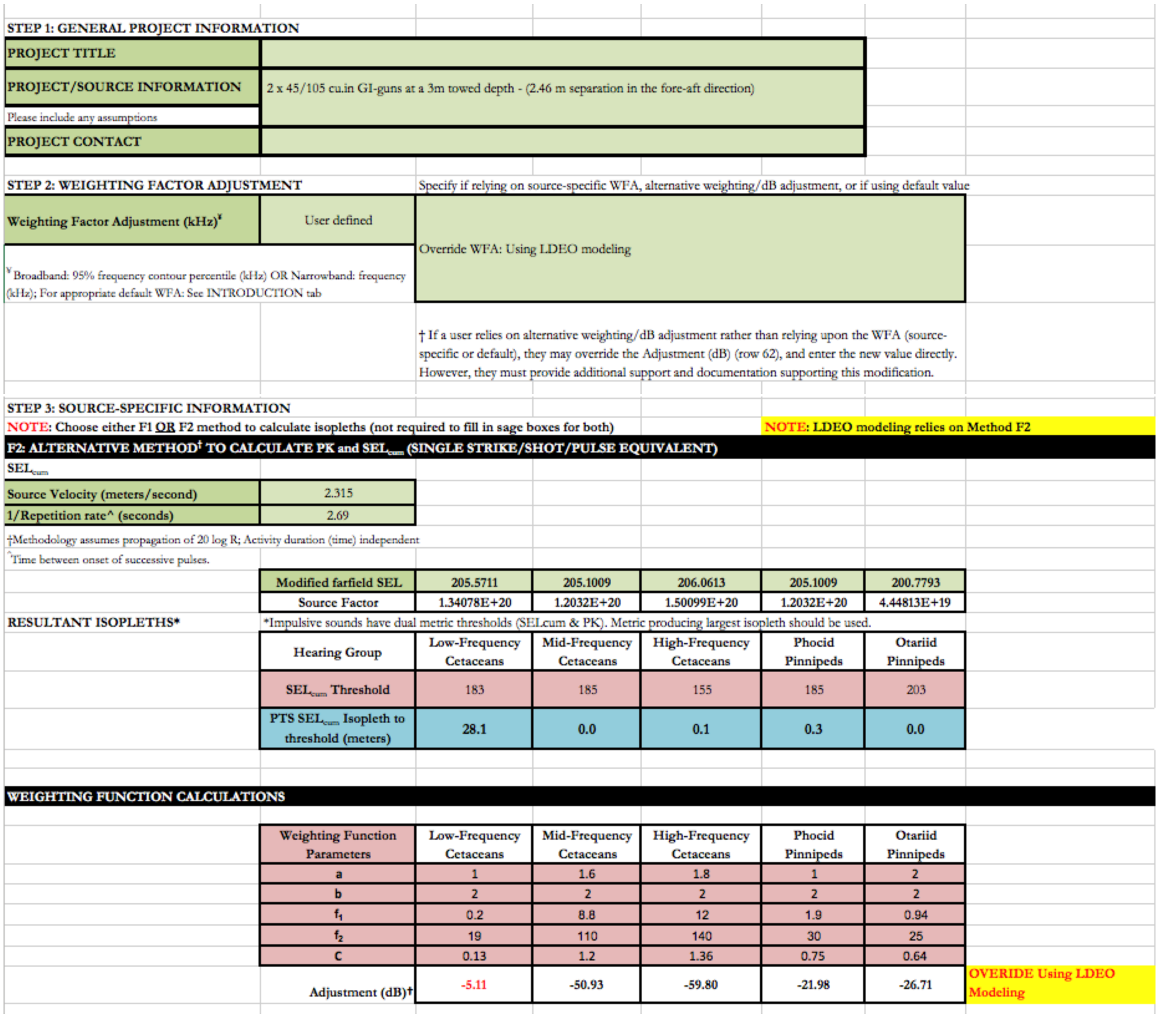
For the two GI airguns, the results for single shot SEL source level modeling are shown in Table A-9. The weighting function calculations, thresholds for $SEL_{cum}$, and the distances to the PTS thresholds for the two GI airguns are shown in Table A-10. Figure A-19 shows the impact of weighting functions by hearing group for the single mitigation airgun. Figures A-20–A-21 show the modeled received sound levels for single shot SEL without applying auditory weighting functions for various hearing groups. Figure A-22 shows the modeled received sound levels for single shot SEL with weighting for LF cetaceans. The thresholds for Peak $SPL_{flat}$ for the two GI airguns, as well as the distances to the PTS thresholds, are shown in Table A-11. Figures A-23–A-25 show the modeled received sound levels to the Peak $SPL_{flat}$ thresholds, for a single shot.

TABLE A-9. Results for single shot SEL source level modeling for the two GI airguns 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)** | 12.0317 | 10.1169 | 357.3250 | 10.1169 | 0.7744 |
| **Modified Farfield SEL*** | 205.5711 | 205.1009 | 206.0613 | 205.1009 | 200.7793 |
| **Distance (m) (with weighting function)** | 7.4621 | N.A. | N.A. | N.A. | N.A. |
| **Adjustment (dB)** | -5.1139 | 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 two 45/105 in$^3$ GI airguns 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** | |
| **PROJECT/SOURCE INFORMATION** | 2 x 45/105 cu.in GI-guns at a 3m towed depth - (2.46 m separation in the fore-aft direction) |
| 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)**$^¥$ | User defined | 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 METHOD† TO CALCULATE PK and SEL$_{cum}$ (SINGLE STRIKE/SHOT/PULSE EQUIVALENT)**

**SEL$_{cum}$**

| | |
|---|---|
| **Source Velocity (meters/second)** | 2.315 |
| **1/Repetition rate^ (seconds)** | 2.69 |

†Methodology assumes propagation of 20 log R; Activity duration (time) independent

^Time between onset of successive pulses.

| | | | | | |
|---|---|---|---|---|---|
| **Modified farfield SEL** | **205.5711** | **205.1009** | **206.0613** | **205.1009** | **200.7793** |
| **Source Factor** | **1.34078E+20** | **1.2032E+20** | **1.50099E+20** | **1.2032E+20** | **4.44813E+19** |

**RESULTANT ISOPLETHS***

*Impulsive sounds have dual metric thresholds (SELcum & 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)** | **28.1** | **0.0** | **0.1** | **0.3** | **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)†** | **-5.11** | **-50.93** | **-59.80** | **-21.98** | **-26.71** | **OVERIDE 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*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-19).

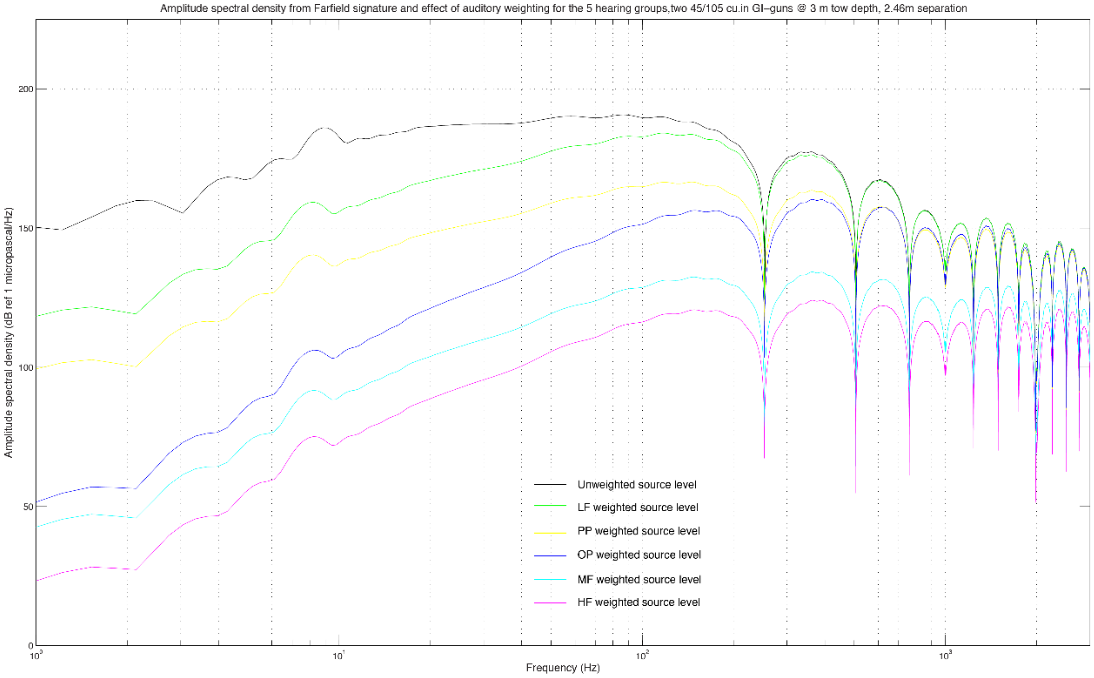


FIGURE A-19. Modeled amplitude spectral density of the two 45/105 in$^3$ GI airguns farfield signature. Amplitude spectral density before (black) and after (colors) applying the auditory weighting functions for LF, MF, and HF cetaceans, Phocid Pinnipeds (PP), and Otariid Pinnipeds (OP). Modeled spectral 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.

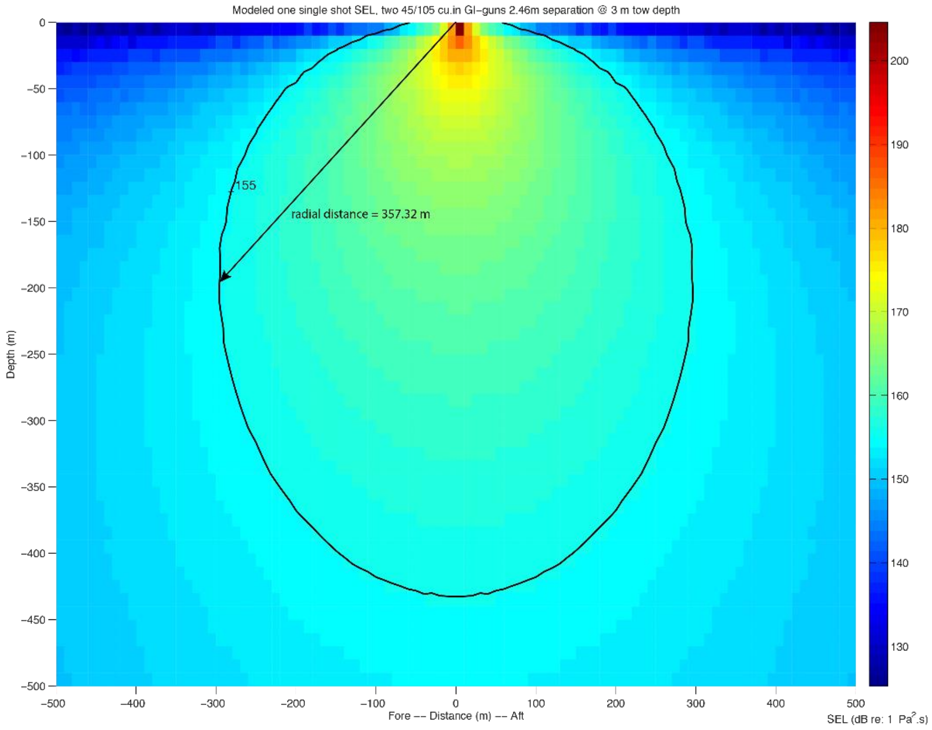


FIGURE A-20. Modeled received sound levels (SELs) in deep water from two 45/105 in$^3$ GI airguns separated by 2.46 m a 3-m tow depth. The plot provides the distance from the geometrical center of the source array to the 155-dB SEL isopleth (357.32 m).

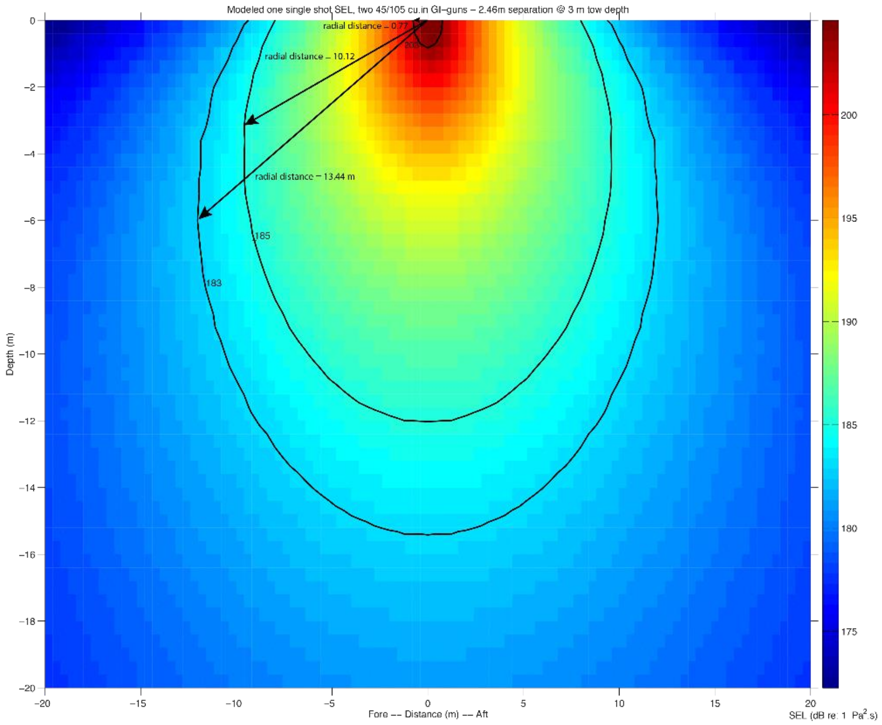


FIGURE A-21. Modeled received sound levels (SELs) in deep water from two 45/105 in$^3$ GI airguns separated by 2.46 m a 3-m tow depth. The plot provides the distance from the geometrical center of the source array to the 183–185 dB and 203 dB SEL isopleths.

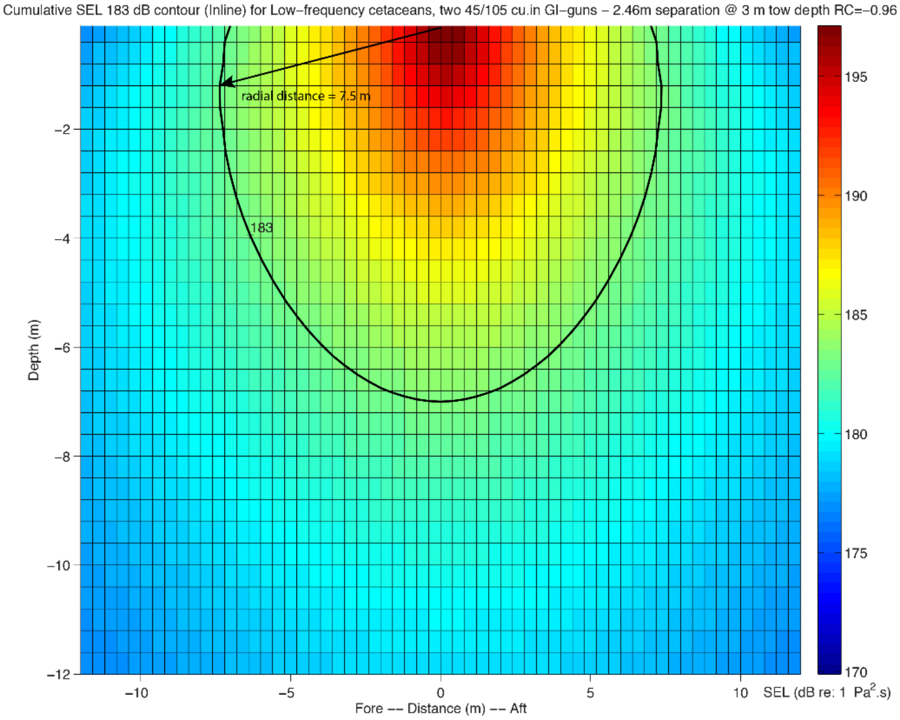


FIGURE A-22. Modeled received sound exposure levels (SELs) from two 45/105 in$^3$ GI airguns separated by 2.46 m a 3-m tow depth, after applying the auditory weighting function for the LF cetaceans hearing group following the NMFS Technical Guidance. The plot provides the radial distance to the 183-dB 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 sea turtles and predicted distances to Level A thresholds for various marine mammal hearing groups that could be received from two 45/105 $in^3$ GI airguns during the proposed USGS seismic surveys off southern Puerto Rico.

| **Hearing Group** | **Low-Frequency Cetaceans** | **Mid-Frequency Cetaceans** | **High-Frequency Cetaceans** | **Phocid Pinnipeds** | **Otariid Pinnipeds/ Sea Turtles** |
|---|---|---|---|---|---|
| **Peak Threshold** | **219** | **230** | **202** | **218** | **232** |
| **Radial Distance to Threshold (m)** | 5.49 | 1.10 | 35.34 | 6.13 | 0.45 |

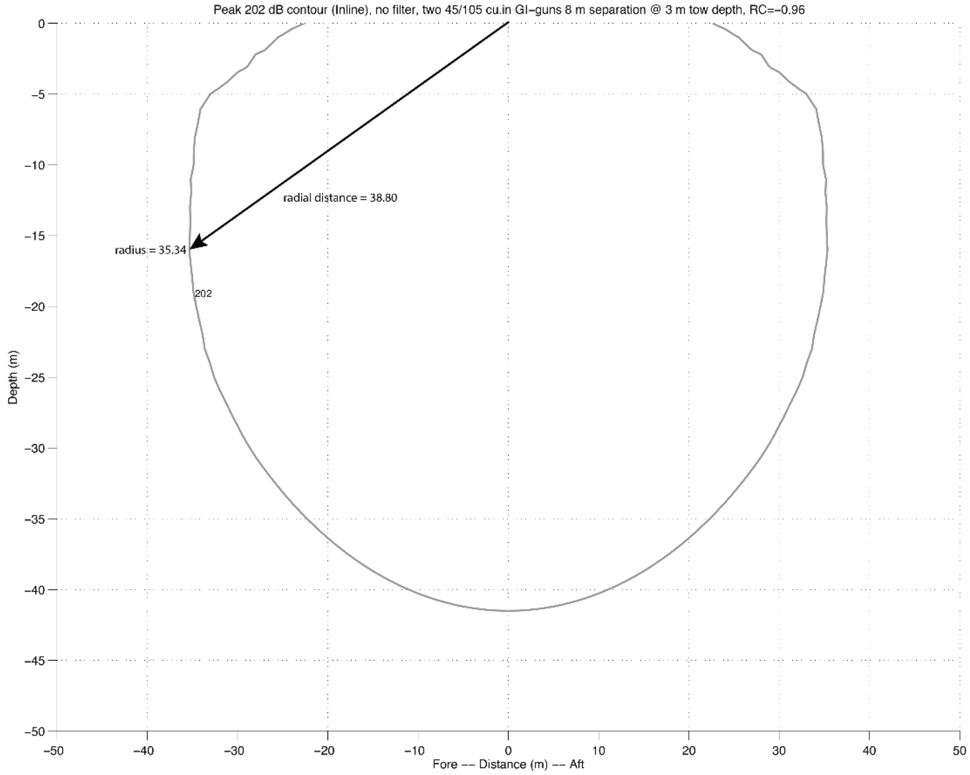


FIGURE A-23. Modeled deep-water received Peak SPL from two 45/105 $in^3$ GI airguns separated by 2.46 m a 3-m tow depth. The plot provides the radial distance from the source geometrical center to the 202-dB Peak isopleth.

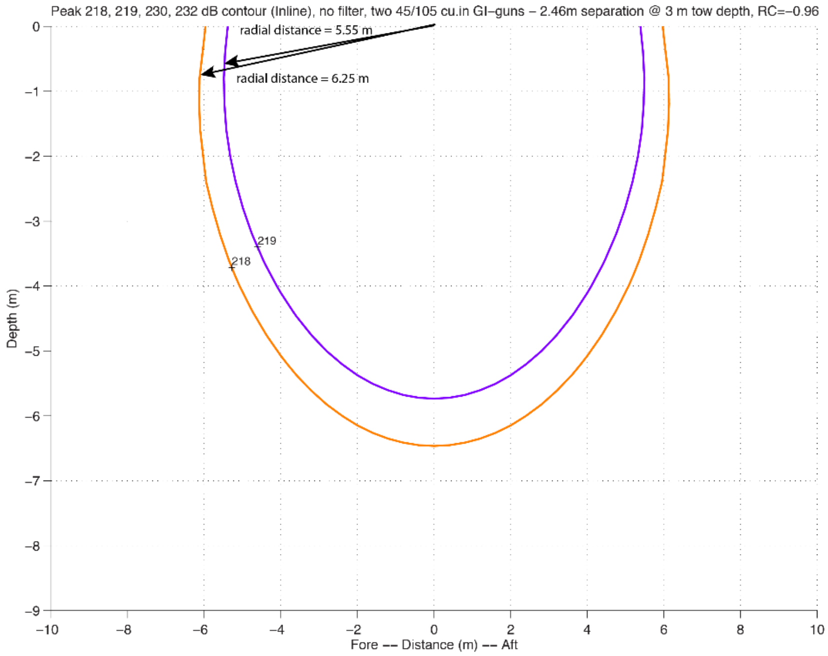


FIGURE A-24. Modeled deep-water received Peak SPL from two 45/105 in$^3$ GI airguns separated by 2.46 m a 3-m tow depth. The plot provides the radial distances from the source geometrical center to the 218 and 219-dB Peak isopleths.

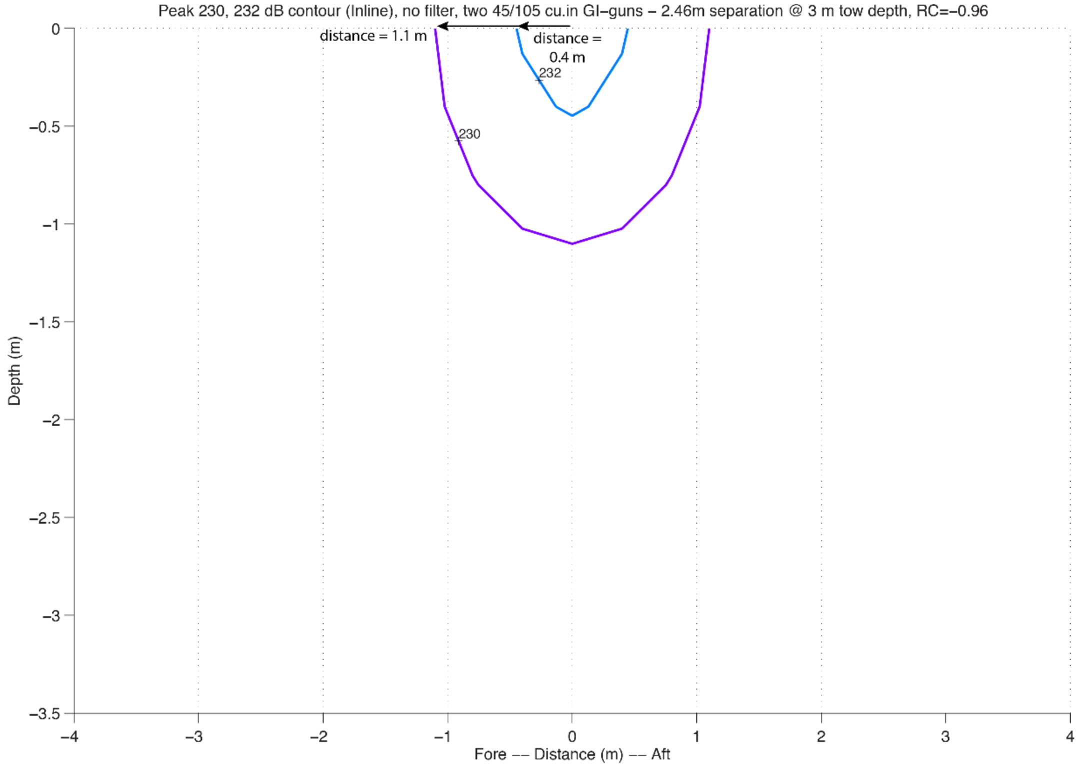


FIGURE A-25. Modeled deep-water received Peak SPL from two 45/105 in$^3$ GI airguns separated by 2.46 m a 3-m tow depth. The plot provides the radial distances from the source geometrical center to the 218 and 219-dB Peak isopleths.

## 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, Balitmore, MD.

Costa, D.P. and T.M. Williams. 1999. Marine mammal energetics. p. 176-217 *In:* J.E. Reynolds III and S.A. Rommel (eds.), Biology of marine mammals. Smithsonian Institution Press, Washington. 578 p.

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.

DoN (U.S. Department of the Navy). 2017. Criteria and thresholds for U.S. Navy Acoustic and Explosive Effects Analysis (Phase III). Technical Report prepared by the U.S. Navy.

Lucke, K., S.B. Martin, and R. Racca. 2020. Evaluating the predictive strength of underwater noise exposure criteria for marine mammals. **J. Acoust. Soc. Am.** 147:3985. doi:10.1121/10.0001412.

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.

Southall, B.L., J.J. Finneran, C. Reichmuth, P.E. Nachtigall, D.R. Ketten, A.E. Bowles, W.T. Ellison, D.P. Nowacek, and P.L. Tyack. 2019. Marine mammal noise exposure criteria: updated scientific recommendations for residual hearing effects. **Aquatic Mamm.** 45(4):411-522.

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

Tougaard, J., K. Beedholm, and P.T. Madsen. 2022. Thresholds for noise induced hearing loss in harbor porpoises and phocid seals. **J. Acoust. Soc. Am.** 151:4252-4263.

# APPENDIX B: MARINE MAMMAL TAKE CALCULATION

# APPENDIX B: MARINE MAMMAL TAKE CALCULATIONS

Level B takes were determined for both the low- and high-energy seismic surveys, whereas Level A takes were only determined for the high-energy surveys. The ensonified areas that were used to calculate Level A and B takes are provided in Appendix C. Marine mammal densities were derived from habitat-based density models from Roberts et al. (2023). The detailed take calculations are shown in Table B-1. Population sizes for marine mammals are unknown for the Caribbean Sea and Puerto Rico and the U.S. Virgin Islands. The percentage of the population estimated to be taken was calculated for each species using the numbers from estimates for the AFTT area (western North Atlantic and GoM) from Roberts et al. (2023), which is the same dataset from which densities were calculated.

## Literature Cited

Hayes, S.A., E. Josephson, K. Maze-Foley, P.E. Rosel, and J. Wallace (eds). 2022. U.S. Atlantic and Gulf of Mexico Marine mammal stock assessments 2021. NOAA Tech. Memo NMFS-NE-288.

NMFS. 2022. Draft U.S. Atlantic and Gulf of Mexico marine mammal stock assessments: 2022. NOAA Tech. Memo. Accessed July 2023 at https://www.fisheries.noaa.gov/s3/2023-01/Draft%202022%20Atlantic%20SARs_final.pdf

Roberts, J.J., T.M. Yack, and P.N. Halpin. 2023. Marine mammal density models for the U.S. Navy Atlantic Fleet Training and Testing (AFTT) study area for the Phase IV Navy Marine Species Density Database (NMSDD). Document version 1.3. Report prepared for Naval Facilities Engineering Systems Command, Atlantic by the Duke University Marine Geospatial Ecology Lab, Durham, NC. Accessed July 2023 at https://seamap.env.duke.edu/models/Duke/AFTT/

TABLE B-2. Take estimates for the low-energy and the high-energy seismic surveys off Puerto Rico.

| | | | | | | Level B Ensonified Area (km²) | | | Level A Ensonified Area (km²) | Level B Takes | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Species | Intermediate 100-1000 m | Deep >1000 m | Stock Abundance North Atlantic[1] | Abundance AFTT Area[2] | Hearing Group | USGS Intermediate 100-1000 m | USGS Deep >1000 m | High-Energy Source Deep >1000 m | Large Source Survey | USGS Intermediate 100-1000 m | USGS Deep >1000 m | High-Energy Source Deep >1000 m | Level B Takes (Both surveys) | Only Level B Takes minus Level A (Both Surveys) | Level A Takes[4] (High-Energy only) | Level B + Level A % of AFTT Area Abundance [5] | Requested Level A+B Take Authorization[6] |
| **LF Cetaceans** | | | | | | | | | | | | | | | | | |
| Humpback whale | 0.004739 | 0.003748 | 1,396 | 4,990 | LF | 428 | 378 | 72,112 | 3,260 | 2 | 1 | 270 | 274 | 262 | 12 | 5.5 | 274 |
| Minke whale | 0.000184 | 0.000835 | 21,968 | 13,784 | LF | 428 | 378 | 72,112 | 3,260 | 0 | 0 | 60 | 61 | 58 | 3 | 0.4 | 61 |
| Bryde's whale | 0.000085 | 0.000088 | | 536 | LF | 428 | 378 | 72,112 | 3,260 | 0 | 0 | 6 | 6 | 6 | 0 | 1.2 | 6 |
| Fin whale | 0.000013 | 0.000006 | 6,802 | 11,672 | LF | 428 | 378 | 72,112 | 3,260 | 0 | 0 | 0 | 0 | 0.4 | 0 | 0.0 | 2[7] |
| Sei whale | 0.000319 | 0.000319 | 6,292 | 19,530 | LF | 428 | 378 | 72,112 | 3,260 | 0 | 0 | 23 | 23 | 22 | 1 | 0.1 | 23 |
| Blue whale | 0.000020 | 0.000020 | 402 | 191 | LF | 428 | 378 | 72,112 | 3,260 | 0 | 0 | 1 | 1 | 1 | 0 | 0.8 | 1 |
| **MF Cetaceans** | | | | | | | | | | | | | | | | | |
| Sperm whale | 0.005312 | 0.006623 | 4,349 | 64,015 | MF | 428 | 378 | 72,112 | 138 | 2 | 3 | 478 | 482 | 481 | 1 | 0.8 | 482 |
| Beaked whales | 0.009887 | 0.007392 | 5,744 | 65,069 | MF | 428 | 378 | 72,112 | 138 | 4 | 3 | 533 | 540 | 539 | 1 | 0.8 | 540 |
| Cuvier's beaked whale [8] | N.A. | N.A. | 5,744 | | MF | 428 | 378 | 72,112 | 138 | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | 179 |
| Blainville's beaked whale [8] | N.A. | N.A. | 10,107 | | MF | 428 | 378 | 72,112 | 138 | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | 179 |
| Gervais' beaked whale [8] | N.A. | N.A. | 10,107 | | MF | 428 | 378 | 72,112 | 138 | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | 179 |
| True's beaked whale | N.A. | N.A. | 10,107 | | MF | 428 | 378 | 72,112 | 138 | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | 3[9] |
| Risso's dolphin | 0.005193 | 0.002232 | 35,215 | 78,205 | MF | 428 | 378 | 72,112 | 138 | 2 | 1 | 161 | 164 | 164 | 0 | 0.2 | 164 |
| Rough-toothed dolphin | 0.006916 | 0.006546 | 136 | 32,848 | MF | 428 | 378 | 72,112 | 138 | 3 | 2 | 472 | 477 | 476 | 1 | 1.5 | 477 |
| Common bottlenose dolphin | 0.081656 | 0.028930 | 62,851 | 418,151 | MF | 428 | 378 | 72,112 | 138 | 35 | 11 | 2,086 | 2132 | 2128 | 4 | 0.5 | 2,132 |
| Pantropical spotted dolphin | 0.013061 | 0.010670 | 6,593 | 321,740 | MF | 428 | 378 | 72,112 | 138 | 6 | 4 | 769 | 779 | 778 | 1 | 0.2 | 779 |
| Atlantic spotted dolphin | 0.021284 | 0.021119 | 39,921 | 259,519 | MF | 428 | 378 | 72,112 | 138 | 9 | 8 | 1,523 | 1540 | 1537 | 3 | 0.6 | 1,540 |
| Spinner dolphin | 0.026713 | 0.026492 | 4,102 | 152,511 | MF | 428 | 378 | 72,112 | 138 | 11 | 10 | 1,910 | 1932 | 1928 | 4 | 1.3 | 1,932 |
| Striped dolphin | 0.001807 | 0.004373 | 67,036 | 412,729 | MF | 428 | 378 | 72,112 | 138 | 1 | 2 | 315 | 318 | 317 | 1 | 0.1 | 318 |
| Clymene dolphin | 0.020654 | 0.021800 | 4,237 | 181,209 | MF | 428 | 378 | 72,112 | 138 | 9 | 8 | 1,572 | 1589 | 1586 | 3 | 0.9 | 1,589 |
| Fraser's dolphin | 0.002539 | 0.002926 | | 19,585 | MF | 428 | 378 | 72,112 | 138 | 1 | 1 | 211 | 213 | 213 | 0 | 1.1 | 213 |
| Common dolphin | 0.001796 | 0.001206 | 172,974 | 473,260 | MF | 428 | 378 | 72,112 | 138 | 1 | 0 | 87 | 88 | 88 | 0 | 0.0 | 88 |
| Short-finned pilot whale [10] | 0.023968 | 0.025140 | 28,924 | 264,907 | MF | 428 | 378 | 72,112 | 138 | 10 | 10 | 1,813 | 1833 | 1830 | 3 | 0.7 | 1,833 |
| Killer whale | 0.000024 | 0.000024 | | 972 | MF | 428 | 378 | 72,112 | 138 | 0 | 0 | 2 | 2 | 2 | 0 | 0.2 | 2 |
| False killer whale | 0.003016 | 0.002983 | 1,791 | 12,682 | MF | 428 | 378 | 72,112 | 138 | 1 | 1 | 215 | 218 | 218 | 0 | 1.7 | 218 |
| Pgymy killer whale | 0.001742 | 0.001782 | | 9,001 | MF | 428 | 378 | 72,112 | 138 | 1 | 1 | 128 | 130 | 130 | 0 | 1.4 | 130 |
| Melon-headed whale | 0.013398 | 0.013531 | | 64,114 | MF | 428 | 378 | 72,112 | 138 | 6 | 5 | 976 | 987 | 985 | 2 | 1.5 | 987 |
| **HF Cetaceans** | | | | | | | | | | | | | | | | | |
| *Kogia* spp. | 0.004750 | 0.005055 | 7,750 | 26,043 | HF | 428 | 378 | 72,112 | 2,731 | 2 | 2 | 365 | 368 | 354 | 14 | 1.4 | 368 |
| Dwarf sperm whale [11] | N.A. | N.A. | 7,750 | | HF | 428 | 378 | 72,112 | 2,731 | N.A. | N.A. | 182 | 184 | 177 | 7 | N.A. | 184 |
| Pygmy sperm whale [11] | N.A. | N.A. | 7,750 | | HF | 428 | 378 | 72,112 | 2,731 | N.A. | N.A. | 182 | 184 | 177 | 7 | N.A. | 184 |
| **Sea Turtle** | | | | | | | | | | | | | | | | | |
| Kemp's Ridley Sea Turtle | | | | | | | | | | | | | | | | | |
| Hawksbill Sea Turtle | N.A. | N.A. | N.A. | N.A. | ST | 75 | 66 | 19,215 | 156 | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. |
| Olive Ridley Sea Turtle | N.A. | N.A. | N.A. | N.A. | ST | 75 | 66 | 19,215 | 156 | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. | N.A. |
| Loggerhead Sea Turtle | 0.00160 | 0.00160 | N.A. | N.A. | ST | 75 | 66 | 19,215 | 156 | 0 | 0 | 31 | 31 | 31 | 0 | N.A. | 31 |
| Green Sea Turtle | 0.00049 | 0.00049 | N.A. | N.A. | ST | 75 | 66 | 19,215 | 156 | 0 | 0 | 9 | 10 | 9 | 0 | N.A. | 10 |
| Leatherback Sea Turtle | 0.00018 | 0.00018 | N.A. | N.A. | ST | 75 | 66 | 19,215 | 156 | 0 | 0 | 3 | 3 | 3 | 0 | N.A. | 3 |

Notes: Some values do not add up exactly due to rounding. Where population sizes are blank, it means none were available. N.A. = not available or not applicable. NA = North Atlantic. GoM = Gulf of Mexico. Pop. = population.

[1] From Hayes et al. (2022) and NMFS (2022).

[2] From Roberts et al. (2023).

[3] Based on population sizes in the AFTT area (U.S. Atlantic and Gulf of Mexico) from habitat-based density modeling by Roberts et al. (2023).

# APPENDIX C: ENSONIFIED AREAS USES FOR TAKE CALCULATIONS

# APPENDIX C: ENSONIFIED AREAS FOR TAKE CALCULATIONS

The ensonified areas that were used to calculate Level A and B takes for the high-energy seismic surveys are detailed in Table C-1, whereas those used to calculate Level B takes for the low-energy surveys are shown in Table C-2.

| Survey Type | Survey Zone | Criterion | Daily Ensonified Area (km$^2$) | Total Survey Days | 25% Increase | Total Ensonified Area (km$^2$) | Relevant Isopleth (m) |
|---|---|---|---|---|---|---|---|
| **Marine Mammals** | | | | | | | |
| OBS | Shallow <100 m | 160 dB | 0 | 7 | 1.25 | 0 | 25,494 |
| OBS | Intermediate 100-1000 m | 160 dB | 89.7 | 7 | 1.25 | 784.6 | 9,468 |
| OBS | Deep >1000 m | 160 dB | 2793.1 | 7 | 1.25 | 24439.6 | 6,733 |
| MCS | Shallow <100 m | 160 dB | 0 | 13 | 1.25 | 0 | 25,494 |
| MCS | Intermediate 100-1000 m | 160 dB | 89.7 | 13 | 1.25 | 1457.2 | 9,468 |
| MCS | Deep >1000 m | 160 dB | 2254.5 | 13 | 1.25 | 36635.0 | 6,733 |
| | **Overall** | **160 dB** | **5226.9** | **19** | **1.25** | **63316.4** | |
| **Sea Turtles** | | | | | | | |
| OBS | Shallow <100 m | 160 dB | 0 | 7 | 1.25 | 0 | 25,494 |
| OBS | Intermediate 100-1000 m | 160 dB | 38.7 | 7 | 1.25 | 338.7 | 9,468 |
| OBS | Deep >1000 m | 160 dB | 753.9 | 7 | 1.25 | 6596.9 | 6,733 |
| MCS | Shallow <100 m | 160 dB | 0 | 13 | 1.25 | 0 | 25,494 |
| MCS | Intermediate 100-1000 m | 160 dB | 38.7 | 13 | 1.25 | 629.0 | 9,468 |
| MCS | Deep >1000 m | 160 dB | 604.8 | 13 | 1.25 | 9828.2 | 6,733 |
| | **Overall** | **160 dB** | **1436.2** | **19** | **1.25** | **17392.8** | |
| **Hearing Groups** | | | | | | | |
| OBS | All zones | LF Cetacean | 133.4 | 7 | 1.25 | 1,167.5 | 320.2 |
| OBS | All zones | MF Cetacean | 5.7 | 7 | 1.25 | 49.5 | 13.6 |
| OBS | All zones | HF Cetacean | 111.8 | 7 | 1.25 | 978.1 | 268.3 |
| OBS | All zones | Otariid | 4.4 | 7 | 1.25 | 38.6 | 10.6 |
| OBS | All zones | Phocid | 18.2 | 7 | 1.25 | 159.2 | 43.7 |
| OBS | All zones | Sea Turtle | 6.4 | 7 | 1.25 | 56.1 | 15.4 |
| MCS | All zones | LF Cetacean | 107.8 | 13 | 1.25 | 1,752.0 | 320.2 |
| MCS | All zones | MF Cetacean | 4.6 | 13 | 1.25 | 74.3 | 13.6 |
| MCS | All zones | HF Cetacean | 90.3 | 13 | 1.25 | 1,467.7 | 268.3 |
| MCS | All zones | Otariid | 3.6 | 13 | 1.25 | 57.9 | 10.6 |
| MCS | All zones | Phocid | 14.7 | 13 | 1.25 | 238.8 | 43.7 |
| MCS | All zones | Sea Turtle | 5.2 | 13 | 1.25 | 84.1 | 15.4 |

TABLE C-2. Areas expected to ensonified during the proposed low-energy USGS surveys off Puerto Rico.

| Survey Zone | Criterion | Daily Ensonified Area ($km^2$) | Total Survey Days | 25% Increase | Total Ensonified Area ($km^2$) | Relevant Isopleth (m) |
|---|---|---|---|---|---|---|
| **Marine Mammals** | | | | | | |
| Deep >1000 m | 160 dB | 100.9 | 3 | 1.25 | 378.4 | 438 |
| Intermediate 100-1000 m | 160 dB | 114.1 | 3 | 1.25 | 427.9 | 657 |
| **Overall** | **160 dB** | **215.0** | **3** | **1.25** | **806.3** | |
| **Sea Turtles** | | | | | | |
| Deep >1000 m | 175 dB | 17.7 | 3 | 1.25 | 66.4 | 78 |
| Intermediate 100-1000 m | 175 dB | 20.0 | 3 | 1.25 | 75.0 | 117 |
| **Overall** | **160 dB** | **37.7** | **3** | **1.25** | **141.4** | |