# Draft Environmental Analysis of Marine Geophysical Research at Reykjanes Ridge, South of Iceland, in the North 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**
4201 Wilson Blvd., Suite 725
Arlington, VA 22230

by

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

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# TABLE OF CONTENTS

Page

# LIST OF FIGURES

Page

# LIST OF TABLES

Page

# ABSTRACT

Researchers from the University of Birmingham, University of Southampton, and University of Cambridge with funding from the United Kingdom's (UK) Natural Environment Research Council (NERC) propose to conduct marine geophysical research off southern Iceland, in the North Atlantic Ocean, during summer 2024 (Proposed Action). The research would include high-energy seismic surveys conducted from the research vessel (R/V) *Marcus G. Langseth* (*Langseth*), which is owned and operated by Lamont-Doherty Earth Observatory (L-DEO) of Columbia University. The proposed two-dimensional (2-D) seismic surveys would occur within International Waters and within Iceland's Exclusive Economic Zone. The surveys would use a 36-airgun towed array with a total discharge volume of approximately (~) 6600 $in^3$ in water >500 m to 3000 m deep.

While not directly funding the research, the U.S. National Science Foundation (NSF) would provide funding support for the vessel and environmental compliance support as part of a ship barter agreement with NERC. Due to NSF's involvement, survey operations would be conducted in accordance with all applicable international and U.S. federal regulations, including IHA and Incidental Take Statement (ITS) requirements. 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 entitled 'IMPULSE: Taking the Pulse of the Icelandic Mantle Plume'. IMPULSE would make the first definite test of the Thermal Plume Pulsing (TPP) model, the shortest predicted time period of transient mantle convections, which has been suggested as a primary driver of some of the most remarkable perturbations to global climate, ecosystems, and the carbon cycle in Earth's history. The North Atlantic V-shaped Ridges (VSRs) are the basis for the TPP model. The proposed seismic surveys would acquire the first ever full crustal seismic profiles across multiple complete VSR cycles.

This Draft Environmental Analysis (EA) addresses NSF's the requirements under Executive Order 12114, "Environmental Effects Abroad of Major Federal Actions", for the proposed federal action in international waters. L-DEO, on behalf of itself, NSF, the University of Birmingham, University of Southampton, and University of Cambridge, 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 Record of Decision (June 2012), referred to herein as PEIS.

Numerous species of marine mammals inhabit the proposed survey area in the North Atlantic Ocean. Under the U.S. ESA, several of these species are listed as ***endangered***, including the North Atlantic right, sei, fin, blue, sperm whales, and the Cape Verde/Northwest Africa DPS of humpback whale, which are managed by NMFS. Other ESA-listed species that could occur in the survey area include the ***endangered*** leatherback sea turtle, the ***endangered*** freira, and the endangered Bermuda petrel.

Potential impacts of the proposed seismic surveys on the environment would be primarily a result of the operation of the airgun array. Other acoustic sources, including 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.

Proposed protection measures designed to mitigate the potential environmental impacts to marine mammals, and ESA-listed sea turtles and seabirds 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; passive acoustic monitoring (PAM) via towed hydrophones during both day and night to complement visual monitoring during the high-energy surveys; and shut downs when marine mammals are detected in or about to enter designated exclusion zones (EZ). The acoustic source would also be shut down in the event an ESA-listed sea turtle or seabird (diving/foraging) would be observed 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.

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, 2018) 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 |
| BFZ | Bight Fracture Zone |
| CBD | Convention on Biological Diversity |
| CGFZ | Charlie Gibbs Fracture Zone |
| CITES | Convention on International Trade in Endangered Species |
| dB | decibel |
| DFO | Canadian Department of Fisheries and Oceans |
| DoN | Department of the Navy |
| DPP | Draft Proposed Program |
| DPS | Distinct Population Segment |
| EA | Environmental Analysis |
| EBSA | Ecologically or Biologically Significant Marine Areas |
| EEZ | Exclusive Economic Zone |
| 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 |
| FMP | Fishery Management Plan |
| FONSI | Finding of No Significant Impact |
| G&G | geological and geophysical |
| GIS | Geographic Information System |
| h | hour |
| HAPC | Habitat Area of Particular Concern |
| hp | horsepower |
| HRG | high-resolution geophysical |
| Hz | Hertz |
| ICES | International Council for the Exploration of the Sea |
| IHA | Incidental Harassment Authorization (under MMPA) |
| in | inch |
| IODP | International Ocean Discovery Program |
| ITS | Incidental Take Statement |
| IUCN | International Union for the Conservation of Nature |
| IWC | International Whaling Commission |
| kHz | kilohertz |
| km | kilometer |
| kt | knot |
| L-DEO | Lamont-Doherty Earth Observatory |
| LFA | Low-frequency Active (sonar) |
| LME | Large Marine Ecosystem |
| m | meter |
| MAFMC | Mid-Atlantic Fishery Management Council |

| | |
|---|---|
| MBES | Multibeam Echosounder |
| MCS | Multi-Channel Seismic |
| MFA | Mid-frequency Active (sonar) |
| MFRI | Marine and Freshwater Research Institute |
| min | minute |
| MMC | Marine Mammal Commission |
| MMPA | (U.S.) Marine Mammal Protection Act |
| MPA | Marine Protected Area |
| ms | millisecond |
| MSC | Marine Stewardship Council |
| NAMMCO | North Atlantic Marine Mammal Commission |
| NEAFC | North East Atlantic Fisheries Commission |
| NEPA | National Environmental Policy Act |
| NEFSC | Northeast Fisheries Science Center |
| NMFS | (U.S.) National Marine Fisheries Service |
| NMS | National Marine Sanctuary |
| nmi | nautical mile |
| NOAA | National Oceanic and Atmospheric Administration |
| NRC | (U.S.) National Research Council |
| NSF | National Science Foundation |
| OBIF | Ocean Bottom Instrumentation Facility |
| OBS | Ocean Bottom Seismometer |
| OCS | Outer Continental Shelf |
| OEIS | Overseas Environmental Impact Statement |
| p or pk | peak |
| PEIS | Programmatic Environmental Impact Statement |
| PI | Principal Investigator |
| PTS | Permanent Threshold Shift |
| PSO | Protected Species Observer |
| QAA | Qualitative Analysis Area |
| rms | root-mean-square |
| ROD | Record of Decision |
| RSPB | Royal Society for the Protection of Birds |
| R/V | research vessel |
| s | second |
| SAFMC | South Atlantic Fishery Management Council |
| SBP | Sub-bottom Profiler |
| SEA | Supplemental Environment Assessment |
| SEL | Sound Exposure Level (a measure of acoustic energy) |
| SMA | Seasonal Management Area |
| SOSUS | (U.S. Navy) Sound Surveillance System |
| SPL | Sound Pressure Level |
| SPUE | Sighting per unit effort |
| t | tonnes |
| TPP | Thermal Plume Pulsing |
| TTS | Temporary Threshold Shift |
| U.K. | United Kingdom |
| UNEP | United Nations Environment Programme |
| UNESCO | United Nations Educational, Scientific and Cultural Organization |
| U.K. | United Kingdom |
| U.S. | United States of America |

| | |
|---|---|
| USCG | United States Coast Guard |
| USGS | United States Geological Survey |
| USFWS | United States Fish and Wildlife Service |
| USWTR | Undersea Warfare Training Range |
| μPa | microPascal |
| VME | Vulnerable Marine Ecosystem |
| vs. | versus |
| VSR | (North Atlantic) V-shaped Ridges |
| WCMC | World Conservation Monitoring Centre |

# I PURPOSE AND NEED

Researchers from the University of Birmingham, University of Southampton, and University of Cambridge, with funding from the U.S. National Science Foundation (NSF), propose to conduct marine geophysical research of the Reykjanes Ridge off southern Iceland, in the North Atlantic Ocean in 2024 (Proposed Action). The research would include high-energy seismic surveys conducted from the research vessel (R/V) *Marcus G. Langseth* (*Langseth*). This Draft Environmental Analysis (EA) was prepared pursuant to Executive Order 12114, “Environmental Effects Abroad of Major Federal Actions”. 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 Record of Decision (NSF 2012), 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 consultation 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, 2018), 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

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

## 1.2 Purpose of and Need for the Proposed Action

As noted in the PEIS, § 1.3, NSF has a continuing need to support marine geophysical research, including seismic surveys that enable scientists to collect data essential to understanding the complex Earth processes beneath the ocean floor. The purpose of the proposed marine geophysical research would be to make the first definite test of the TPP model, which has been suggested as a primary driver of major perturbations to global climate, ecosystems, and the carbon cycle in Earth’s history. The Proposed Action would meet the agency’s critical need to foster an understanding of Earth processes.

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[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.

## 1.3 Background of NSF-supported Marine Seismic Research

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

## 1.4 Regulatory Setting

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

- Executive Order 12114 – *Environmental effects abroad of major Federal actions*;
- *Marine Mammal Protection Act* (MMPA) of 1972 (16 USC 1631 *et seq.*); and
- *Endangered Species Act* (ESA) of 1973 (16 USC ch. 35 §1531 *et seq.*).

# II ALTERNATIVES INCLUDING PROPOSED ACTION

In this Draft EA, two alternatives are evaluated: (1) Proposed Action: conducting the proposed marine geophysical research, including seismic surveys, and associated issuance of an 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 marine geophysical research, is described in the following subsections.

### 2.1.1 Project Objectives and Context

Principle Investigator (PI) from University of Birmingham, and Co-PIs from the University of Southampton and University of Cambridge, propose to conduct marine geophysical research off southern Iceland in the North Atlantic Ocean during summer 2024, using seismic surveying capability of R/V *Langseth* (Fig. 1).

The main goal of the high-energy seismic program proposed by the Principal Investigator (PI) Dr. S. Jones (University of Birmingham), and Co-PIs Professor T. Henstock (University of Southampton) and Professor N. White (University of Cambridge), is to make the first definite test of the TPP model, the shortest predicted time period of transient mantle convections, which has been suggested as a primary driver of major perturbations to global climate, ecosystems, and the carbon cycle in Earth's history.

IMPULSE has four main objectives:

1. Acquire the first ever full crustal seismic profiles across multiple complete VSR cycles.
2. Generate the first true record of magma productivity fluctuations that built the VSRs by correcting crustal thickness for the effect of tectonic "noise" from crustal accretion processes.
3. Model co-located records of magma productivity and composition to verify the TPP model.
4. In collaboration with international partners, test the relationship between transient mantle convection and global environmental change during the Pliocene onset of the Northern Hemisphere Glaciation and the Paleocene/Eocene Thermal Maximum events.

To achieve project goals of the seismic surveys, the PIs propose to utilize the seismic surveying capabilities of R/V *Langseth*, as well as Ocean Bottom Seismometers (OBS).

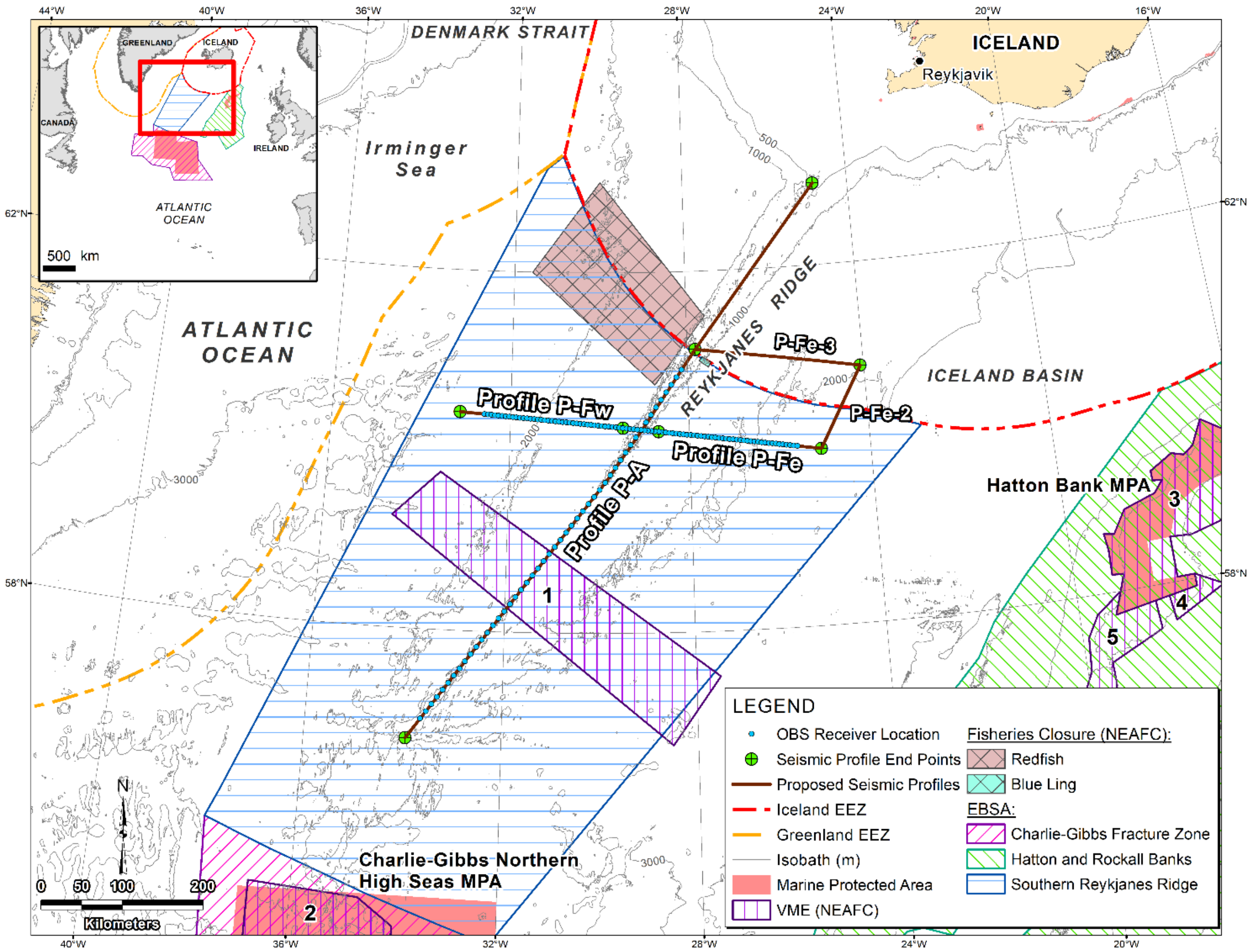

FIGURE 1. Location of the proposed seismic surveys, OBS deployments, and marine conservation areas in the North Atlantic Ocean. Representative survey tracklines are included in the figure; however, the tracklines could occur anywhere within the survey area. Numbered sites correspond to the following Vulnerable Marine Ecosystems (VMEs): (1) Northern Mid-Atlantic Ridge, (2) Mid Mid-Atlantic Ridge, (3) Hatton Bank, (4) Hatton Bank Area 1, and (5) Hatton Bank Area 2. EBSA = Ecologically or Biologically Significant Marine Areas. MAP = Marine Protected Area. NEAFC = North East Atlantic Fisheries Commission. Sources: CBD (2023); NEAFC (2023); Protected Planet (2023).

## 2.1.2 Proposed Activities

### 2.1.2.1 Location of the Survey Activities

The proposed marine seismic surveys would occur within the survey area depicted in Figure 1, ~56–63°N, 24–34°W, and would occur within International Waters and within Iceland's Exclusive Economic Zone (EEZ). The water depths in the survey area range from 500–3000 m. The proposed survey would take place more than 100 km from any coast. Representative seismic 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, the seismic surveys could occur anywhere within the survey area and general coordinates noted above.

#### 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 conducted by L-DEO and would use conventional seismic methodology. The surveys would involve one source vessel, R/V *Langseth*, which would tow a 36-airgun array with a discharge volume of ~6600 in$^3$ at a depth of 10–12 m. The receiving system would consist of a 15-km long solid-state hydrophone streamer (solid flexible polymer – not gel or oil filed) and ~150 deployments using a total of 50 OBSs. The airguns would fire at a shot interval of ~24 s (~50 m) during multi-channel seismic (MCS) reflection surveys with the hydrophone streamer and at a 60 s (~154.5 m) interval during OBS seismic refraction surveys. 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 surveys would consist of two primary seismic profiles (P-A and P-F) that would be acquired once for MCS reflection data and then again for OBS refraction data (see Fig. 1); profile line segments without OBS deployments (see Fig. 1) would only be shot once for MCS reflection data. There would be a total of ~2754 km of seismic acquisition, including 1662 km of 2-D MCS seismic reflection data and 1092 km of OBS refraction data. Profile P-A has a northeast-southwest orientation and is ~851 km long. Profile P-F (west to east) would be acquired in two separate parts (P-Fe and P-Fw, 246.5 km each) given the number of OBS deployments (150) and the number of OBSs available (50) from the UK Ocean-Bottom Instrumentation Facility (OBIF) pool. Most of the effort (~78%) would occur in deep water (>1000 m); the remainder would occur in intermediate water depths (100–1000 m). There could be additional seismic operations associated with 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.

In addition to the operations of the airgun array, other acoustic sources, including a multibeam echosounder (MBES), sub-bottom profiler (SBP), and an 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

The proposed high-energy survey with the 36-airgun array would be expected to take place during summer 2024 for a period of ~38 days; this includes 9 days of MCS seismic operations, 5 days of seismic operations with OBSs, 17 days of OBS deployment and retrieval, 3 days of streamer deployment and retrieval, and 4 days of transit. R/V *Langseth* would likely leave out of and return to port in Reykjavik, Iceland (~200 km from the survey area). Equipment deployment and recovery times would vary and occur anytime during the planned survey, except during transit. 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 long timeline associated with the ESA Section 7 consultation and IHA processes, not all research project 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 gross tonnage of R/V *Langseth* is 3834 t. 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* tows the airgun array and hydrophone streamer, the turning rate of the vessel would be limited to five degrees per minute. Thus, the maneuverability of the vessel would be limited during operations with the streamer. Protected species observers (PSOs) would have a 360-degree view from the vessel's observation tower.

### 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 would be spaced 8 m apart. 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 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 10–12 m, and the shot interval would be ~24 s (~50 m) during MCS seismic reflection surveys and 60 s (~154.5 m) 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 firing, a brief pulse of sound with a duration of ~0.1 s would be emitted. The airguns would be silent during the intervening periods. During operations, airguns would be operated 24/7 for multiple days to meet science objectives unless maintenance or mitigation measures warranted.

**36-Airgun Array Specifications**

| | |
|---|---|
| Energy Source | Thirty-six Bolt airguns of 40–360 $in^3$, 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 |
| Firing Pressure | ~2000 psi |

### 2.1.2.6 Ocean Bottom Seismometer Description

Refraction surveys would be acquired along both profiles (see Fig. 1). Up to 50 OBSs from the OBIF group would be deployed at a time, then recovered, serviced and redeployed on subsequent profiles, for a total of 150 deployments. Each deployment/recover should take ~24 h. Profile P-F would be shot in two separate parts (P-Fe and P-Fw) given the OBIF pool size and an OBS spacing of ~4 km. OBS spacing along profile P-A would be 11 km. The OBIF OBSs have a height of ~1 m and a maximum diameter of ~1 m, with concrete anchors (typically ~0.3 m x 0.3 m x 0.2 m) and/or steel anchors (up to 1 m × 1 m × 0.1 m). The concrete anchors disintegrate faster than the steel anchors. While the concrete anchors have some steel embedded as an attachment point for the OBS, they would degrade, mainly to sand. All OBSs would be recovered by the end of the survey. To retrieve the OBSs, the instrument is released to float to the surface via an acoustic release system from the anchor, which is not retrieved.

### 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* continuously during the proposed surveys, including during transits. 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 anchor which is not retrieved.

The MBES is a hull-mounted system operating at 10.5–13 kHz (usually 12 kHz). The transmitting beam width would be 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 would be 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 would be operated to provide information about the near sea floor sedimentary features and the bottom topography that would be mapped simultaneously by the MBES. The beam would be transmitted as a 27-degree cone, which would be directed downward by a 3.5-kHz tansducer in the hull of R/V *Langseth*. The nominal power output would be 10 kilowatts, but the actual maximum radiated power would be 3 kilowatts or 222 $\text{dB}_{\text{rms}}$ re 1 µPa at 1 m. The ping duration would be up to 64 milliseconds, and the ping interval would be one second. A common mode of operation is to broadcast five pulses at one-second intervals followed by a five-second pause. The SBP would be 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 35–1200 kHz, with a maximum source level of 224 dB re 1µPa$_{-1}$ m over a conically-shaped 30° beam and a ping rate of 0.7 Hz.

For OBS retrieval, an acoustic release transponder (pinger) is used to interrogate the instrument at a frequency of 8–11 kHz, and a response is received at a frequency of 11.5–13 kHz. The burn-wire release assembly is then activated, and the instrument is released to float to the surface from the anchor which is not retrieved.

## 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 surveys could not be met using a smaller source. The 36-airgun energy source was determined to be the lowest practical source to meet the scientific objectives, including penetrating crustal depths.

***Survey Location and Timing*****.—**The PIs, along with L-DEO and NSF, considered 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 toothed whales and delphinids are expected to occur in the survey area year-round, most baleen whales would primarily occur there during summer; however, they are expected to be uncommon in the region. Thus, summer was determined to be the most practical timing for the proposed surveys based on weather conditions, operational requirements, and availability of researchers.

***Mitigation Zones*****.—**During the planning phase, mitigation zones for the proposed marine seismic surveys using the 36-airgun array (at a tow depth of up to 12 m) were not derived from the farfield signature but based on modeling by L-DEO for both the exclusion zones (EZ) for Level A takes and full mitigation zones (160 dB re 1µPa$_{rms}$) for Level B takes. 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 airgun source 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).

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. 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 sea turtles.

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, 2018), and sea turtles (DoN 2017). Per the *Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing* (NMFS 2016a, 2018), 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 LF cetaceans, and Peak SPL is used for all other marine mammal hearing groups. The PTS thresholds for the MCS surveys are shown in Table 2; the PTS thresholds for the refraction surveys with OBSs are shown in Table 3.

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). For other recent high-energy seismic surveys conducted by L-DEO, NMFS required protected species observers (PSOs) to establish and monitor a 500-m EZ for shut downs and to monitor an additional 500-m buffer zone beyond the EZ for marine mammals and a 150-m EZ for sea turtles. Enforcement of mitigation zones via shutdowns would be implemented as described below.

TABLE 1. Predicted distances to behavioral disturbance sound levels ≥160-dB re 1 μPa$_{rms}$ and ≥175-dB re 1 μPa$_{rms}$ that could be received during the proposed surveys of the Reykjanes Ridge off southern Iceland. The 160-dB criterion applies to all hearing groups of marine mammals (Level B harassment), and the 175-dB criterion applies to sea turtles.

| Source and Volume | Tow Depth[1] (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 |
|---|---|---|---|---|
| 4 strings, 36 airguns, 6600 in$^3$ | 12 | >1000 m | 6,733[2] | 1,864[2] |
| | | 100–1000 m | 10,100[3] | 2,796[3] |

[1] Maximum tow depth was used for conservative distances. [2] Distance is based on L-DEO model results. [3] Distance is based on L-DEO model results with a 1.5 × correction factor between deep and intermediate water depths.

TABLE 2. Level A (PTS) threshold distances for different marine mammal hearing groups for the 36-airgun array based on a speed of 4.1 kts and a shot interval of ~24 s (50 m) for the MCS surveys. 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 |

TABLE 3. Level A (PTS) threshold distances for different marine mammal hearing groups for the 36-airgun array based on a speed of 5 kts and a shot interval of 60 s (154.5 m) m for the refraction surveys with OBSs. 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$_{cum}$** | **103.6** | 0 | 0.3 | 3.4 | 0 | 5.0 |
| **PTS Peak** | 38.9 | **13.6** | **268.3** | **43.7** | **10.6** | **10.6** |

### 2.1.3.2 Operational Phase

Marine mammals and sea turtles are known to occur in the proposed survey area. However, the number of individual animals expected to be approached closely during the proposed activities would be 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 PSOs for marine mammals, ESA-listed sea turtles and seabirds (diving/foraging) near the vessel, and observing for potential impacts of acoustic sources on fish; (2) passive acoustic monitoring (PAM); (3) PSO data and documentation; and (4) mitigation during operations (speed or course alteration; shut down and ramp up procedures; and special mitigation measures for rare species, species concentrations, and sensitive habitats).

It would be unlikely that concentrations of large whales would be encountered within the 160-dB isopleth, but if they were, they would be avoided.

During daytime, the PSO(s) would scan the area around the vessel systematically with reticle binoculars (e.g., 7×50 Fujinon), Big-eye binoculars (25×150), and with the naked eye. During darkness, night vision devices (NVDs) would be available (ITT F500 Series Generation 3 binocular-image intensifier or equivalent), when required.

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

***Shut down Procedures***.—The operating airguns would be shut down if a marine mammal was seen within or approaching the EZ. Shut downs would not be required for small dolphins that are most likely to approach the vessel. The airgun array would be shut down if ESA-listed sea turtles or seabirds (diving/foraging) were observed within a 150-m designated EZ.

Following a shut down, airgun activity would not resume until the marine mammal, ESA-listed sea turtle or seabird has cleared the EZ. The animal would be considered to have cleared the EZ if

- it was visually observed to have left the EZ, or
- it was not seen within the zone for 15 min in the case of small odontocetes, pinnipeds, ESA-listed seabirds and sea turtles, or
- it was not seen within the zone for 30 min in the case of mysticetes and large odontocetes, including sperm, pygmy sperm, dwarf sperm, and beaked whales.

The airgun array would be ramped up gradually after a shut down for marine mammals but would not be required for ESA-listed sea turtles or seabirds. 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. It is proposed that 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. As previously noted, for shut downs implemented for sea turtles and ESA-listed seabirds, no ramp up would be required, as long as the animal was no longer observed within the EZ.

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 or ESA-listed sea turtles/seabirds (diving/foraging) are sighted, a shut down would be implemented, respectively, as though the full array were operational. Ramp up would only commence at night or during poor visibility if the EZ has been monitored acoustically with PAM for 30 min prior to the start of operations without any marine mammal detections during that period.

The proposed operational mitigation measures are standard for seismic cruises. Independently contracted PSOs would be on board the survey vessel with rotating shifts to allow at least one PSO and one trained observer to monitor for marine species during daylight hours; two PSOs would monitor during ramp ups and other times when feasible during daylight hours. Observers would undertake training (e.g., U.S. Navy PSO training) and by the lead PSO prior to undertaking monitoring duties. During the high-energy surveys, one PSO would conduct PAM during day- and night-time seismic operations. Monitoring and mitigation measures are further 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, per the IHA and Biological Opinion. With the proposed monitoring and mitigation provisions, potential effects on most, if not all, individual marine mammals and sea turtles would be expected to be limited to minor behavioral disturbance. Those potential effects would be expected to have negligible impacts both on individuals and on the associated species and stocks. Ultimately, survey operations would be conducted in accordance with all applicable international 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 4). Under the “No Action” alternative, NSF would not support L-DEO to conduct the proposed research operations. From NMFS’ perspective, pursuant to its obligation to grant or deny permit applications under the MMPA, the “No Action” alternative entails NMFS denying the application for an IHA. If NMFS were to deny the application, L-DEO would not be authorized to incidentally take marine mammals. If the research was not conducted, the “No Action” alternative would result in no disturbance to marine mammals attributable to the Proposed Action. Although the No-Action Alternative is not considered a reasonable alternative because it does not meet the purpose and need for the Proposed Action, it is included and carried forward for analysis in § 4.3.

## 2.3 Alternatives Considered but Eliminated from Further Analysis

Table 4 provides a summary of the Proposed Action and the alternatives.

### 2.3.1 Alternative E1: Alternative Location

IMPULSE will collaborate with the International Ocean Discovery Program (IODP) to test the hypothesis that deep-water flow in the North Atlantic Ocean has been modulated by thermal pulsing of the Icelandic Mantle Plume through late Miocene-Pliocene time, and with the PORO-CLIM[2] project test the hypothesis that thermal pulsing of the Icelandic Mantle Plume is a viable mechanism to explain the Paleocene-Eocene Thermal Maximum global climate change event. The North Atlantic VSRs in this region are the basis for the TPP model. Under this alternative the VSRs would be imaged in alternative locations within the Iceland Basin and Irminger Sea, within the general area between 40°W and 20°W, and between 58°N and 63°N (Fig. 1). However, any such alternative locations would not meet the purpose of the survey, because the scientific objectives and associated analysis program depend on the seismic lines being coincident with existing seabed sample sites. The only suitable sample sites are a set of seafloor dredge samples along profile P-A, and IODP Expedition 395 boreholes along profile P-F. Alternative locations

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[2] https://www.poro-clim.org/about

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

| Proposed Action | Description |
|---|---|
| Proposed Action: Conduct marine geophysical surveys and associated activities on the Reykjanes Ridge off southern Iceland | Under this action, research activities are proposed to study Earth processes and would involve marine seismic surveys. Active seismic operations would be expected to take 14 days, and an additional 24 operational days would be expected for transit; equipment deployment and retrieval, maintenance, and retrieval; weather; marine mammal activity; and other contingencies. The affected environment, environmental consequences, and cumulative impacts of the proposed activities are described in § III and IV. The standard monitoring and mitigation measures identified in the PEIS would apply, along with any additional requirements identified by regulating agencies in the U.S. All necessary permits and authorizations, including an IHA, would be requested from regulatory bodies. |
| Alternatives | Description |
| Alternative 1:<br>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 shed light on some of the most remarkable perturbations to global climate, ecosystems, and the carbon cycle in Earth's history, would not be collected; in addition, 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 | IMPULSE would collaborate with IODP to test the hypothesis that deep-water flow in the North Atlantic Ocean has been modulated by thermal pulsing of the Icelandic Mantle Plume through late Miocene-Pliocene time, and with the PORO-CLIM project to test the hypothesis that thermal pulsing of the Icelandic Mantle Plume is a viable mechanism to explain the Paleocene-Eocene Thermal Maximum global climate change event. The North Atlantic VSRs in this region are the basis for the TPP model, which would be examined during the proposed project. Alternative locations would not meet the purpose of the survey, because the scientific objectives and associated analysis program depend on the seismic lines being coincident with existing seabed sample sites at the proposed survey location. |
| 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. |

would not meet the purpose of the survey, because the scientific objectives and associated analysis program depend on the seismic lines being coincident with existing seabed sample sites at the proposed survey location.

### 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 survey area. These resources are identified in § III, and the potential impacts to these resources are discussed in § IV. Initial review and analysis of the Proposed Action determined that the following resource areas did not require further analysis in this EA:

- *Air Quality/Greenhouse Gases*—Vessel emissions would result from the proposed activity; however, these short-term emissions would not result in any exceedance of Federal Clean Air standards. Emissions would be expected to have a negligible impact on the air quality within the proposed survey area. To reduce impacts on air quality, R/V *Langseth* uses Ultra-Low Sulfur fuel (<15 ppm Sulfur) and employs a Ship Energy Efficiency Management Plan to reduce and minimize fuel consumption (e.g., speed optimization) resulting in overall lower emissions.
- *Land Use*—All activities are proposed to occur in the marine environment. Thus, no changes to current land uses or activities in the proposed survey area would result from the project;
- *Safety and Hazardous Materials and Management*—No hazardous materials would be generated or used during the proposed activities. All project-related wastes would be disposed of in accordance with international, U.S. state and federal requirements.
- *Geological Resources (Topography, Geology and Soil)*—The proposed project would result in very minor disturbance to seafloor sediments from OBS deployments during the surveys; small steel or concrete anchors would not be recovered but would degrade over time. However, the proposed activity would not adversely affect geologic resources.
- *Water Resources*—No discharges to the marine environment that would adversely affect marine water quality are expected in the survey area. Therefore, there would be no impacts to water resources resulting from the proposed Project activity.
- *Terrestrial Biological Resources*—All proposed activities would occur in the marine environment and would not impact terrestrial biological resources;
- *Visual Resources*—No visual resources would be expected to be negatively impacted as the proposed activities would be short-term. During operations, the vessel would not be within the viewshed of the coast.
- *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. Airgun sounds would have no effects on solid structures. Other human activities in the area around the survey vessel would include fishing and other vessel traffic. Fishing and potential impacts to fishing are described in further detail in Sections 3.7 and 4.1.2, respectively. No other socioeconomic impacts would be anticipated as result of the proposed activities.

## 3.1 Oceanography

The proposed survey area is located along the Reykjanes Ridge, which is a shallow portion of the Mid-Atlantic Ridge. The Mid-Atlantic Ridge spans the Atlantic Ocean from north to south and forms a divergent plate boundary at the meeting place of the North Atlantic and Eurasian tectonic plates (Quam and Campbell 2020). The Reykjanes Ridge portion of the Mid-Atlantic Ridge spans southwest off the southern coast of Iceland. It is an area featuring seamounts and significant volcanic activity (Hoskuldsson et al. 2007). The Reykjanes Ridge has a strong influence on the North Atlantic subpolar gyre circulation (Petit et al. 2018). There are two fracture zones along the Reykjanes Ridge – the Bight Fracture Zone (BFZ) and the Charlie Gibbs Fracture Zone (CGFZ). The summit of Reykjanes Ridge is ~300 m deep, and at the CGFZ, it deepens to more than 3000 m (Petit et al. 2018).

The Reykjanes Ridge is located between the Irminger Sea to the west and the Iceland Basin to the east. Along the eastern side of the Reykjanes Ridge runs the East Reykjanes Current which originates from the northern portion of the Iceland Basin (Koman et al. 2020). This current terminates ~900 km southwest from its creation where it passes westward over the Reykjanes Ridge and into the Irminger Sea (Koman et al. 2020). In the Irminger Sea, warm water from the Atlantic meets with colder water from the Arctic. The Irminger Current is a warm current with a northward flow that splits into two branches west of Iceland. The western branch connects with cold, low salinity water in the East Greenland (Polar) Current and returns southward through the Denmark Strait (Hansen and Osterhus 1998).

The proposed survey area spans three benthic habitats – the Reykjanes Ridge, the Irminger Basin area to the west, and Iceland Basin to the east. In the Iceland Basin, water depth ranges from 900 m to 2800 m. The basin area is characterized by Modified North Atlantic Waters with surface waters that are highly productive (Meißner et al. 2014). The deeper water in the basin experiences an anti-clockwise current. This basin acts as a passageway for Iceland – Scotland Overflow Water that travels from across the Iceland – Faroe Ridge and makes its way into the Irminger Basin (Meißner et al. 2014). Benthic topography in the basin is characterized by homogenous soft sands (Meißner et al. 2014).

In the spurs of the Reykjanes Ridge (near the shelf), the water depth is 282 m to 305 m. Currents here vary with distance from shore; closer to shore, there is the Icelandic Coastal Current, off from that the Icelandic Coastal Undercurrent exists, and furthest from shore is the Icelandic Slope Current (Meißner et al. 2014). This region has water temperatures of >6°C. Benthic topography is made up of soft sediment (muddy sand) and few larger stones (Meißner et al. 2014).

The Irminger Basin has a depth of 1625 m to 2546 m. The deep area of the basin holds Labrador Sea Water, and the shallower area holds Modified North Atlantic Waters. The Icelandic – Scotland Overflow Water that flows in from the Iceland Basin subsequently forms Atlantic Deep Water, which mixes considerably with the Labrador Sea Water (Meißner et al. 2014). The circulation in the basin is generally anti-clockwise. The benthic topography in this area appears to range from soft sediment (sandy mud) with an absence of stones to sand with small black stones (Meißner et al. 2014).

## 3.2 Protected Areas

The proposed survey would occur within the Southern Reykjanes Ridge Ecologically or Biologically Significant Marine Area (EBSA). Other EBSAs in the vicinity of the survey area include the CGFZ EBSA ~200 km to the south and the Hatton and Rockall Banks EBSA ~300 km to the east (Fig. 1). There are no marine protected areas (MPAs) that overlap the proposed survey area. The closest MPAs are the Charlie-Gibbs North High Seas and Charlie-Gibbs South High Seas MPAs ~200 km to the south and the

Hatton Bank MPA ~365 km to the east.  The North East Atlantic Fisheries Commission (NEAFC) has also closed several Vulnerable Marine Ecosystems (VMEs) to bottom fishing in the region in order to protect substrates that support corals and sponges (ICES 2023).  In addition, there are two currently-active NEAFC Fisheries Closures which are in close proximity to the northern part of seismic profile P-A; the Irminger Sea Closure is for redfish, and the closure for blue ling is seasonal.

***Southern Reykjanes Ridge EBSA*.—**The Reykjanes Ridge, characterized by its unique geomorphological features and its isolation due to the presence of the Iceland-Scotland Overflow Water, stands as a distinct and ecologically significant region within the North Atlantic (Shor et al. 1980).  The majority of the rock in this area is volcanic, serving as both the region's base and a rigid substrate for the colonization of benthic communities, including habitat-forming and vulnerable species.  Cold-water corals, sponge aggregations, and natural coral rubble on the Ridge provide essential shelter, nursery, and feeding grounds for a diverse array of species (Roberts et al. 2009; Maldonado et al. 2016).  The ridge contributes to enhanced mixing in this region, resulting increased productivity (CBD 2023).  Additionally, the ridge plays a crucial role in the life history of the calanoid copepod *Calanus finmarchicus*, which occupies a vital niche in the broader marine food web (Gislason et al. 2007, 2008).  Emerging evidence suggests the presence of rare and unique species, such as elasmobranchs *Bathyraja pallida* and *B. richardsoni*, as well as the Greenland shark (*Solmiosus microcephalus*), signifying the area's potential as a hotspot for biodiversity (Hareide and Garnes 2001).

***Hatton and Rockall Banks EBSA*.—**The Hatton and Rockall Banks EBSA is located in the North-East Atlantic, ~400–500 km southeast of Iceland.  This area encompasses the seabed and pelagic zones shallower than 3000 m, covering the Rockall and Hatton Banks, as well as the Rockall-Hatton Basin situated between these geological features (CBD 2019).  This area serves as critically important habitat for a wide range of cold-water coral species, including black corals, bamboo corals, and hard and soft corals, forming various vital ecosystems like coral reefs, carbonate mounds, and coral gardens, all of which are categorized as threatened and declining habitats by the OSPAR Commission (CBD 2019).  However, the distribution of cold-water coral has significantly declined over the past three decades due to factors such as slow growth rates and long generation times (Carreiro-Silva et al. 2013).  The region's marine biodiversity extends to a variety of vertebrate species, encompassing surface-feeding seabirds, baleen whales, fast-swimming predatory fish, toothed cetaceans, and deep-diving whales (CBD 2019).

***Charlie-Gibbs Fracture Zone EBSA*.—**Fracture zones are topographic features in the ocean that arise from plate tectonics.  The CGFZ is an unusual left lateral strike-slip double transform fault in the North Atlantic Ocean, forming the deepest connection between the northwest and northeast Atlantic (CBD 2019).  It is the most prominent interruption of the Mid-Atlantic Ridge between the Azores and Iceland, and the only fracture zone between Europe and North America with such an offset (Fleming et al. 1970). This area's geological complexity, characterized by steep walls, deep trenches, and irregular terrain, fosters the presence of diverse and fragile ecosystems, including deep-sea corals, sponges, and various species of fish and marine mammals (Miller et al. 2012).  It is home to deep-sea sponge aggregations and cold-water corals and is the only extensive hard substrate for propagating benthic suspension feeders off continental shelves and isolated seamounts (CBD 2019).  It serves as an important hub for migration and foraging for species such as sei whales, sperm whales, and leatherback turtles (Fock et al. 2004; Youngbluth et al. 2008; Skov et al. 2008; Olsen et al. 2009; Prieto et al. 2014).  The Mid Mid-Atlantic Ridge VME is located within this EBSA.

***Charlie-Gibbs North High Seas and Charlie-Gibbs South High Seas Marine Protected Areas*.—** The Charlie-Gibbs North and South High Seas MPAs were designated by the OSPAR Commission in 2012 and 2010, respectively (OSPAR 2017). These adjoining MPAs overlap most of the NEAFC Middle Mid-Atlantic Ridge Closure Area (Fig. 1). The North and South Seas MPAs encompass sensitive habitats with high natural biological productivity, and are important nursery, juvenile, or spawning areas for several species (OSPAR 2012). The North High Seas MPA hosts a variety of fish, mammal, and turtle species, including orange roughy, gulper shark, leafscale gulper shark, Portuguese dogfish, blue whale, and leatherback sea turtle (OSPAR 2012). Despite the wide ranges of these species, the ecological significance of the Charlie-Gibbs North MPA lies in its unique location within the Sub-Polar Frontal Zone, which enhances primary and secondary productivity in the water column. The Mid Mid-Atlantic Ridge VME is located within this MPA. The South High Seas MPA is also habitat for the above-mentioned species, along with coral gardens, deep-sea sponge aggregations, *Lophelia pertusa* reefs, and seamounts (OSPAR 2010).

## 3.3 Marine Mammals

Twenty cetacean species (14 odontocetes and 6 mysticetes) and five pinniped species could occur near the proposed survey area south of Iceland (Table 5). Six of the 25 marine mammal species are listed under the ESA as ***endangered***: the North Atlantic right, blue, fin, sei, sperm whales, and Cape Verde/Northwest Africa DPS of humpback whales. Although the ***endangered*** bowhead whale (*Balaena mysticetus*) occurs in arctic waters of the North Atlantic, it is not included in this analysis. Similarly, the ***threatened*** Arctic subspecies of ringed seal (*Phoca hispida hispida*) is not discussed further, as its distribution range does not typically overlap the proposed survey area.

General information on the taxonomy, ecology, distribution and movements, and acoustic capabilities of baleen whales, toothed whales, and pinnipeds are given in § 3.6.1, § 3.7.1, and § 3.8.1, of the PEIS. The general distributions of mysticetes, odontocetes, and pinnipeds in this region of the Northwest Atlantic Ocean are discussed in the Northern Atlantic/Iceland Qualitative Analysis Area (QAA) in § 3.6.3, § 3.7.3, and § 3.8.3 of the PEIS, respectively. The rest of this section focuses on species distribution in and near the proposed survey area in offshore waters off southern Iceland.

### 3.3.1 Mysticetes

#### 3.3.1.1 North Atlantic Right Whale (*Eubalaena glacialis*)

The North Atlantic right whale occurs primarily in the continental shelf waters of the eastern U.S. and Canada, from Florida to the Gulf of St. Lawrence (Winn et al. 1986; Jefferson et al. 2015; Hayes et al. 2023). There is a general seasonal north-south migration between feeding and calving areas (Gaskin 1982). The migration route between the Cape Cod spring/summer feeding grounds and the Georgia/Florida winter calving grounds is known as the mid-Atlantic corridor, and whales move through these waters regularly in all seasons (Reeves and Mitchell 1986; Winn et al. 1986; Kenney et al. 2001; Reeves 2001; Knowlton et al. 2002; Whitt et al. 2013). The majority of sightings (94%) along the migration corridor are within 56 km of shore (Knowlton et al. 2002).

During the summer and into fall (June–November), right whales are most commonly seen on feeding grounds in Canadian waters off Nova Scotia, with peak abundance during August, September, and early October (Gaskin 1987). Some right whales, including mothers and calves, remain on the feeding grounds through the fall and winter. However, the majority of the right whale population leaves the feeding grounds for unknown wintering habitats and returns when the cow-calf pairs return. The majority of the right whale population is unaccounted for on the southeastern U.S. winter calving ground, and not all reproductively-

TABLE 5. The habitat, occurrence, population sizes, and conservation status of marine mammals that could occur in or near the proposed survey area in the North Atlantic Ocean.

| Species | Habitat | Occurrence in Survey Area* | Abundance in Western North Atlantic[1] | Abun-dance for AFTT[2] | US ESA[3] | IUCN[4] | CITES[5] |
|---|---|---|---|---|---|---|---|
| ***Mysticetes*** | | | | | | | |
| North Atlantic right whale | Mainly coastal and shelf waters, also offshore | Rare | 340 | 711 | E | CR | I |
| Fin whale | Coastal, pelagic | Uncommon | 6,802 | 11,672 | E | VU | I |
| Common minke whale | Coastal, pelagic | Uncommon | 21,968[6] | 13,784 | NL | LC | I |
| Sei whale | Coastal, pelagic | Uncommon | 6,292[7] | 19,530 | E | EN | I |
| Blue whale | Coastal, shelf, pelagic | Uncommon | 402[8] | 191 | E | EN | I |
| Humpback whale<br>Cape Verde/Northwest Africa DPS | Mainly nearshore and banks | Uncommon | 1,396[10]<br>11,570[11] | 4,990 | NL/E[17] | LC | I |
| ***Odontocetes*** | | | | | | | |
| Sperm whale | Usually pelagic and deep seas | Uncommon | 5,895[12] | 64,015 | E | VU | I |
| Northern bottlenose whale | Pelagic, slopes | Uncommon | unk/19,500[13] | 1,056 | NL | NT | I |
| Cuvier's beaked whale | Pelagic, slopes | Uncommon | 4,670 | 65,069[18] | NL | LC | II |
| Blainville's beaked whale | Pelagic, slopes | Rare | 2,936 | 65,069[18] | NL | LC | II |
| Sowerby's beaked whale | Pelagic, slopes | Rare | 492 | 65,069[18] | NL | LC | II |
| Risso's dolphin | Waters with depths of 400-1000 m | Uncommon | 44,067 | 78,205 | NL | LC | II |
| Common Bottlenose dolphin | Continental shelf, coastal, offshore | Uncommon | 64,587[14] | 418,151 | NL | LC | II |
| Striped dolphin | Off the continental shelf | Rare | 48,274 | 412,729 | NL | LC | II |
| White-beaked dolphin | Shelf, pelagic | Uncommon | 536,016 | 2,627 | NL | LC | II |
| Atlantic white-sided dolphin | Coastal, shelf | Common | 93,233 | 175,299 | NL | LC | II |
| Common dolphin | Coastal, pelagic | Uncommon | 93,100 | 473,260 | NL | LC | II |
| Killer whale | Widely distributed | Uncommon | unk / 15,000[15] | 972 | NL | DD | II |
| Long-finned pilot whale | Mostly pelagic | Common | 39,215 | 264,907[19] | NL | LC | II |
| Harbor porpoise | Mostly coastal | Uncommon | 85,765 | 94,583 | NL | LC | II |
| ***Pinnipeds*** | | | | 150,075[20] | | | |
| Hooded seal | Pack ice, pelagic | Uncommon | unk/ 600,000[16] | N.A. | NL | VU | NL |
| Harp seal | Pack ice, pelagic | Uncommon | 7.6 million | N.A. | NL | LC | NL |
| Bearded seal | Pack ice, pelagic | Rare | 500,000- 1 million[16] | N.A. | NL | LC | NL |
| Gray seal | Coastal | Rare | 27,911 | N.A. | NL | LC | NL |
| Harbor seal | Coastal | Rare | 61,336 | N.A. | NL | LC | NL |

N.A. = not available. unk = unknown based on the Draft 2023 Marine Mammal Stock Assessment Reports for the U.S. Atlantic and Gulf of Mexico.

* Occurrence in area at the time of the survey; based on professional opinion and available data including sightings and densities.

[1] Abundance for North Atlantic from the DRAFT 2023 Mexico Marine Mammal Stock Assessment Reports for U.S. Atlantic and Gulf of (NOAA 2024) unless otherwise indicated.

[2] Abundance estimates for the Atlantic Fleet Testing and Training (AFTT) Area from Roberts et al. (2023).

[3] U.S. *Endangered Species Act*: E = endangered, NL = not listed.

[4] International Union for the Conservation of Nature Red List of Threatened Species version 2022-2 – Global ranking: CR = critically endangered; EN = endangered; VU = vulnerable; NT = near threatened; LC = least concern; DD = data deficient.
[5] 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.
[6] Canadian East Coast.
[7] Nova Scotia.
[8] Minimum population size for Western North Atlantic.
[10] Gulf of Maine.
[11] Entire North Atlantic (Stevick et al. 2003).
[12] North Atlantic.
[13] 2017 estimate for the U.K., Iceland, and Faroe Islands (NAMMCO 2023).
[14] Offshore stock.
[15] 2001 estimate for the North Atlantic between Faroe Islands and Canada (NAMMCO 2023).
[16] NAMMCO (2023).
[17] Mostly animals from the non-listed West Indies DPS, but some could be from the endangered Cape Verde/Northwest Africa DPS (e.g., Jann et al. 2003; Bettridge et al. 2015).
[18] Beaked whale guild.
[19] Pilot whale guild.
[20] Seal guild.

active females return to the area each year (Kraus et al. 1986; Winn et al. 1986; Kenney et al. 2001). Other wintering areas have been suggested, based on sparse data or historical whaling logbooks; these include the Gulf of St. Lawrence, Newfoundland and Labrador, coastal waters of New York and between New Jersey and North Carolina, Bermuda, and Mexico (Payne and McVay 1971; Aguilar 1986; Mead 1986; Lien et al. 1989; Knowlton et al. 1992; Cole et al. 2009; Patrician et al. 2009).

The North Atlantic right whale occurred historically off southeast Greenland (Knowlton et al. 1992) and has been detected there visually and acoustically more recently, in particular during 2007 and 2008 (Mellinger et al. 2011; Davis et al. 2017). There have also been sightings in the Azores during winter (Silva et al. 2012), suggesting that there could be a remaining central or eastern sub-population. However, right whales have not been sighted during summer or fall surveys near the Mid-Atlantic Ridge in the North Atlantic (e.g., Holst 2004; Waring et al. 2008). Sigurjónsson et al. (1989) reported one sighting to the north of the proposed survey area at 63.3°N, 32.5°W during July 1987, and Sigurjónsson et al. (1989) reported another sighting southwest of the proposed survey area at 52.7°N, 38.6°W in August of 1989. A sighting of a right whale was also made northwest of Reykjavik, Iceland, in July 2018 (Bragg 2018; Hamilton et al. 2020). Nonetheless, the North Atlantic right whale is expected to be rare in the proposed survey area because of the small population size and the fact that it spends most of its time in nearshore feeding areas during the summer.

#### 3.3.1.2 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).

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). Some individuals from the North

Atlantic migrate to Cape Verde to breed (e.g., Wenzel et al. 2009); however, 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). Feeding areas have no DPS status (Bettridge et al. 2015; NMFS 2016b). According to Hayes et al. (2020), NMFS is 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).

Several humpback sightings have been recorded during summer in the proposed survey area, but most records are north of the survey area (Sigurnjónsson et al. 1985, 1989, 1991; Pike et al. 2002, 2005, 2010a, 2019a; Víkingsson et al. 2002; Gunnlaugsson et al. 2004; Paxton et al. 2009; Smith and Pike 2009; Vigness-Raposa et al. 2010; NAMMCO 2023). During 1987–1995, 32 sightings were recorded for Icelandic and adjacent waters north of 60° during summer (Sigurjónsson and Vikingsson 1997). Aerial surveys off western Iceland documented additional sightings north of the proposed survey area (Pike et al. 2005, 2008a, 2009a, 2010a, 2019b; Paxton et al. 2009; Gunnlaugsson et al. 2012). There are also whaling records for the summer off southwestern Iceland, north of the proposed survey area (Sigurnjónsson and Gunnlaugsson 1990). Waring et al. (2008) recorded humpback whales during a summer survey along the Mid-Atlantic Ridge south of the proposed survey area at ~53°N and 40°W, and Hansen et al. (2018) reported sightings off southeast Greenland from August to September. In the OBIS database, there are numerous records of humpback whales in the waters around Iceland for June to October; however, there are no records in the OBIS database within the proposed survey area (OBIS 2023).

#### 3.3.1.3 Common Minke Whale (*Balaenoptera acutorostrata scammoni*)

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 migrate north of 30°N from March–April and migrate south from Iceland from late September through October (Risch et al. 2014; Víkingsson and Heide-Jorgensen 2015).

Víkingsson and Heide-Jorgensen (2015) reported on a satellite-tagged minke whale that traveled through the proposed survey area during late summer 2004. Sightings within the survey area were also recorded during June and July of 2015 (Pike et al. 2019a). Risch et al. (2014) recorded a minke whale pulse train on an acoustic recorder in the study area in October 2007. Waring et al. (2008) recorded a minke whale during a summer survey along the Mid-Atlantic Ridge south of the proposed survey area at ~53°N, 40°W, and a sighting was made just north of the proposed survey area during July 2012 (Ryan et al. 2013).

Although several minke whale sightings have been made in the survey area, most sightings have been reported to the north (Sigurnjónsson et al. 1985, 1989, 1991; Vikingsson et al. 2002; Gunnlaugsson 1991; Pike et al. 2009b, 2010b; NAMMCO 2023). Aerial surveys off western Iceland, north of the proposed survey area, reported minke whale sightings during the summer from 1986 to 2016 (Pike et al. 2008a, 2009a, 2019b; Gunnlaugsson et al. 2012). There are also whaling records off southwestern Iceland during summer, north of the proposed survey area, from 1979 to 1988 (Sigurnjónsson and Gunnlaugsson 1990). Sightings have also been reported off southeast Greenland from August to September (Hansen et al. 2018). In the OBIS database, there are numerous records of minke whales in the waters around Iceland during June–November; one sighting was made during June 2006 at 53.3°N, 40.9°W, but there are no records within the proposed survey area (OBIS 2023).

#### 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). Habitat suitability models indicate that sei whale distribution is related to cool water with high chlorophyll levels (Palka et al. 2017; Chavez-Rosales eta al. 2019). 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).

In the North Atlantic, there are three sei whale stocks: Nova Scotia, Iceland-Denmark Strait, and Eastern (Donovan 1991). They sei whale undertakes seasonal migrations to feed in subpolar latitudes during summer and returns to lower latitudes during winter to calve (Gambell 1985; Horwood 2018). On summer feeding grounds, sei whales associate with oceanic frontal systems (Horwood 1987). Sei whales that have been tagged in the Azores have been reported to travel to the Labrador Sea, where they spend extended periods of time presumably feeding (Olsen et al. 2009; Prieto et al. 2010, 2014). 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). During the winter, sei whales have been seen from South Carolina south into the Gulf of Mexico and the Caribbean (Rice 1998); however, the location of sei whale wintering grounds in the North Atlantic is unknown (Víkingsson et al. 2010).

Sei whales were the most commonly sighted species during a summer survey along the Mid-Atlantic Ridge from Iceland to north of the Azores, including sightings within the proposed survey area; the greatest number of sightings occurred at the Charlie Gibb Fracture Zone, at ~52°N (Waring et al. 2008). Sei whales were also sighted within the survey area at ~60°N during July 2012 (Ryan et al. 2013). Numerous sightings have been reported in the waters around Iceland during summer shipboard surveys, but few have been made in the proposed survey area (Sigurnjónsson et al. 1985, 1989, 1991; Víkingsson et al. 2002, 2009a; Gunlaugsson et al. 2004; Pike et al. 2019a). Summer aerial surveys documented sightings during 1986–2016 off western Iceland, north of the proposed survey area (Pike et al. 2009a, 2019b). There have also been reported catches of sei whale off western Iceland, north of the survey area, during summer (Sigurnjónsson and Gunnlaugsson 1990; Víkingsson et al. 2015; OBIS 2023). In the OBIS database, there are numerous whaling records for the waters around Iceland, especially during July; several records are located within the proposed survey area (OBIS 2023).

#### 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). 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 extends south along the Mid-Atlantic Ridge. The four feeding stocks in the Northwest Atlantic currently recognized by the North Atlantic Marine Mammal Commission (NAMMCO 2023) are located off West Iceland (in the Central Atlantic), Eastern Greenland, Western Greenland, and Eastern Canada; there are an additional three stocks in the eastern Atlantic.

In the western North Atlantic, higher densities are typically found north of 35°N especially during spring and summer, with lower densities south of 35°N (Edwards et al. 2015). Edwards et al. (2015) reported fin whale sightings in the survey area and the waters around Iceland during June to August. A fin whale was tracked traveling through the survey area off southern Iceland after being tagged in the Azores; it did not appear to be foraging while migrating northward (Silva et al. 2013). During July 2012, fin whales were seen near the Mid-Atlantic Ridge at ~60°N (Ryan et al. 2013). Possible fin whale sightings were made near 60°N and 27°W during the summer 2023 Reykjanes Mantle Convection and Climate IODP Expedition 395 (B. Stockmaster, IODP, pers. comm., 4 December 2023). Waring et al. (2008) reported fin whale sightings south of the proposed survey area during a survey of the Mid-Atlantic Ridge during summer 2004. Additional sightings have been made during the summer in the waters around Iceland, including within the survey area (Sigurnjónsson et al. 1985, 1989, 1991; Víkingsson et al. 2002, 2009b, 2015; Pike et al. 2004, 2005, 2008b, 2019a; NAMMCO 2023). Summer aerial surveys have documented sightings off western Iceland, north of the proposed survey area (Pike et al. 2005, 2008a, 2009a, 2019b; Gunnlaugsson et al. 2012; Víkingsson et al. 2015). Hansen et al. (2018) recorded sightings off southeast Greenland during August to September. Whaling catches were also reported off western Iceland, north of the proposed survey area, during June to September (Sigurnjónsson and Gunnlaugsson 1990; Víkingsson et al. 2015). In the OBIS database, there are several thousand whaling records for the waters around Iceland, with several records located within the proposed survey area (OBIS 2023).

### 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).

Numerous blue whale sightings have been made in the waters around Iceland, including several sightings within the proposed survey area (Sigurnjónsson and Vikingsson 1997; Sigurnjónsson et al. 1989; Vikingsson et al. 2002; Gunnlaugsson et al. 2004; Pike et al. 2019a); one sighting was recorded during summer 1989 at ~60°N, 25°W (Sigurnjónsson et al. 1991). A blue whale was tracked traveling through the survey area off southern Iceland after being tagged in the Azores (Silva et al. 2013). Blue whales were seen during a survey along the Mid-Atlantic Ridge between 40° and 40°N during summer 2004 (Waring et al. 2008). Blue whale sightings have also been made during summer aerial surveys off western Iceland, north of the proposed survey area (Pike et al. 2005, 2009a). Whaling ships also made catches of blue whales between June and September off southwest Iceland, north of the proposed survey area (Sigurnjónsson and Gunnlaugsson 1990). In the OBIS database, there is one blue whale record for the proposed survey area near the western end of profile P-Fw; this record was made during the summer (OBIS 2023). There are an additional three records north of the proposed survey area for summer (OBIS 2023).

## 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 were the second most commonly sighted cetacean species during a summer survey along the Mid-Atlantic Ridge during summer 2004, with most sightings occurring north of ~52°N; sightings were made in the proposed survey area (Waring et al. 2008). NAMMCO (2023) has also reported sightings of sperm whales within the survey area. Numerous shipboard surveys during summer have reported sightings of sperm whales in the waters around Iceland, including the proposed survey area (Sigurnjónsson et al. 1985, 1989, 1991; Vikingsson et al. 2002; Gunnlaugsson et al. 2004, 2009; Pike et al. 2019a). Aerial surveys have documented sperm whale sightings during the summer off western Iceland, north of the proposed survey area (Pike et al. 2009a, 2019b). Whaling ships reported sperm whales off southwest Iceland, north of the survey area, during summer (Sigurnjónsson and Gunnlaugsson 1990). Hansen et al. (2018) also reported sightings off southeast Greenland from August to September. There are several thousand records of sperm whales in the OBIS database for the waters around Iceland; most of these are whaling records that occurred between May to December, including several within the proposed survey area (OBIS 2023).

### 3.3.2.2 Northern Bottlenose Whale (*Hyperoodon ampullatus*)

The northern bottlenose whale is found only in the North Atlantic, from the subarctic to ~30°N (Jefferson et al. 2015). Northern bottlenose whales are most common in deep waters beyond the continental shelf or over submarine canyons, usually near or beyond the 1000-m isobath (Jefferson et al. 2015). NAMMCO (2023) reported sightings within the proposed survey area, and possible sightings were made near 60°N and 27°W during the summer 2023 Reykjanes Mantle Convection and Climate IODP Expedition 395 (B. Stockmaster, IODP, pers. comm., 4 December 2023). Northern bottlenose whales have also been sighted during July–August in the waters around Iceland, including within the survey area (Sigurnjónsson and Vikingsson 1997; Sigurnjónsson et al. 1989, 1991; Vikingsson et al. 2002; Gunnlaugsson et al. 2004; Pike et al. 2019a). Whaling ships also made catches during summer off southwest Iceland, north of the survey area (Sigurnjónsson and Gunnlaugsson 1990). In the OBIS database, there are several records in the Irminger Sea, northwest of the survey area, during summer, and there are four records to the south along the Mid-Atlantic Ridge between 52.8 and 54.3°N (OBIS 2023).

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

Cuvier's beaked whale is probably the most widespread and common of beaked whales, although it is not found in high-latitude polar waters (Heyning 1989; Baird 2018). 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 2018). 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, short surfacing intervals, and tendency to avoid vessels all help to explain the infrequent sightings (Barlow and Gisiner 2006; Shearer et al. 2019). There is one record for June 2006 south of the survey area at 51.4°N, 43.1°W (Silva et al. 2014). There are no records for the survey area in the OBIS database (OBIS 2023).

#### 3.3.2.4 Sowerby's Beaked Whale (*Mesoplodon bidens*)

Sowerby's beaked whale occurs in cold temperate waters of the Atlantic from the Labrador Sea to the Norwegian Sea, and south to New England, the Azores, and Madeira (Mead 1989). Sowerby's beaked whale is known primarily from strandings, which are more common in the eastern than the western North Atlantic (MacLeod et al. 2006). It is mainly a pelagic species and is found in deeper waters of the shelf edge and slope (Mead 1989). Several sightings of unidentified beaked whales have been made in the survey area, but none were identified to species (Sigurnjónsson et al. 1991; Gunnlaugsson et al. 2004; Waring et al. 2008). There are no records of Sowerby's beaked whale in the OBIS database for the proposed survey area (OBIS 2023).

#### 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. Several sightings of unidentified beaked whales have been made in the survey area, but none were identified to species (Sigurnjónsson et al. 1991; Gunnlaugsson et al. 2004; Waring et al. 2008). There are no records of Blainville's beaked whale in the OBIS database for the proposed survey area (OBIS 2023).

#### 3.3.2.6 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 Gulf of Mexico, 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). 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). 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). Pike et al. (2019a) made sightings of common bottlenose dolphins in the Irminger Sea/Denmark Strait in June–July 2015. However, there are no records of bottlenose dolphins for the proposed survey area in the OIBS database (OBIS 2023).

#### 3.3.2.7 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. 1994; 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 western North Atlantic, the striped dolphin occurs from Nova Scotia to the Gulf of Mexico and south to Brazil (Würsig et al. 2000). Sightings were made along the Mid-Atlantic Ridge between 41° and 49°N during June 2004, but there are no records for the proposed survey area (OBIS 2023).

#### 3.3.2.8 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 North Atlantic, this species is distributed from Newfoundland to Brazil (Kruse et al. 1999). Jefferson et al. (2014) reported offshore sightings in deep offshore waters southeast of the proposed survey area. In the OBIS database, there are no records for the survey area, but there are two records for Denmark Strait in July (OBIS 2023).

#### 3.3.2.9 Atlantic White-sided Dolphin (*Lagenorhynchus acutus*)

The Atlantic white-sided dolphin occurs in cold temperate and subpolar waters in the North Atlantic; in the western Atlantic, its range is from ~38°N to southern Greenland (Jefferson et al. 2015). It appears to prefer deep waters of the outer shelf and slope but can also occur in shallow and pelagic waters (Jefferson et al. 2015). Several sightings have been reported within the proposed survey area (Gunnlaugsson et al. 2004), and sightings were also made along the Mid-Atlantic Ridge between 35° and 60°N, including within the survey area (Doksæter et al. 2008; Waring et al. 2008). Pike et al. (2019a) reported several sightings in the waters south of Iceland during June–July 2015, but not within the proposed survey area. Sightings of *L. acutus* and *Lagenorhynchus spp.* were made during aerial surveys in the summer off western Iceland, north of the survey area (Donovan and Gunnlaugsson 1989; Pike et al. 2009b). There are four records for the survey area in the OBIS database for June at ~60°N, 29°W (OBIS 2023).

#### 3.3.2.10 White-beaked Dolphin (*Lagenorhynchus albirostris*)

The white-beaked dolphin occurs in cold temperate and subpolar regions of the North Atlantic; its range extends from Cape Cod to southern Greenland in the west and Portugal to Svalbard in the east (Jefferson et al. 2015; Kinze 2018). It appears to prefer deep waters along the outer shelf and slope but can also occur in shallow areas and far offshore (Jefferson et al. 2015). There are four main high-density centers in the North Atlantic, including (1) the Labrador Shelf, (2) Icelandic waters, (3) waters around Scotland, and (4) the shelf along the coast of Norway (Kinze 2018).

Gunnlaugsson et al. (2004) reported white-beaked dolphin sightings in the proposed survey area during summer from 1987 to 2003. Sightings were also made within the survey area during shipboard surveys during June–July 2015 (Pike et al. 2019a). White-beaked dolphins were observed on the Mid-Atlantic Ridge at ~56°N during June 2004 (Doksæter et al. 2008; Waring et al. 2008). NAMMCO (2023) also reported sightings off southwest Iceland, including within the survey area. Rasmussen et al. (2013) reported sightings off southwest Iceland, north of the proposed survey area, during August to February. During aerial surveys off western Iceland, north of the survey area, numerous sightings of *Lagenorhynchus sp.* (mostly *L. albirostris*) were made (Gunnlaugsson et al. 2012; Pike et al. 2008a, 2009a, 2019b). Sightings have also been reported off southeast Greenland in August and September (Hansen et al. 2018). In the OBIS database, there are several records for the Irminger Sea and adjacent waters off Iceland, including near but not within the survey area (OBIS 2023).

#### 3.3.2.11 Common dolphin (*Delphinus delphis 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; the pelagic range in the North Atlantic extends south to ~35ºN (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). Sightings have been recorded near the survey area at ~55°N during June and July (Cañadas et al. 2009; Pike et al. 2019a). However, there are no sightings for the proposed survey area in the OBIS database, and no sightings have been recorded in the Irminger Sea (OBIS 2023). There are two records for Denmark Strait for July–August (OBIS 2023).

#### 3.3.2.12 Long-finned Pilot Whale (*Globicephala melas*)

There are two species of pilot whales – the long-finned pilot whale (*G. melas*) is distributed antitropically, whereas the short-finned pilot whale (*G. macrorhynchus*) is found in tropical, subtropical, and warm temperate waters (Olson 2018). Pilot whales are generally nomadic and occur on the shelf break, over the slope, and in areas with prominent topographic features (Olson 2018). Based on NAMMCO (2023), there are several records within the proposed survey area. Sightings were also made on the Mid-Atlantic Ridge between 45° to 61°N (Doksæter et al. 2008; Waring et al. 2008).

Numerous sightings have been reported for the survey area and waters adjacent to Iceland (Sigurnjónsson et al. 1985, 1989, 1991; Vikingsson et al. 2002; Gunnlaugsson et al. 2004; Pike et al. 2019a,c; NAMMCO 2023). Sightings were made near 60°N and 27–28°W during the summer 2023 Reykjanes Mantle Convection and Climate IODP Expedition 395 (B. Stockmaster, IODP, pers. comm., 4 December 2023). Sightings have also been made during aerial surveys off western Iceland, north of the survey area, during the summer (Pike et al. 2008a, 2009a, 2019b). In addition, catches have been made by whaling ships off southwest Iceland, north of the survey area, during June–September (Sigurnjónsson and Gunnlaugsson 1990). Sightings have also been recorded off southeast Greenland in August and September (Hansen et al. 2018). There are several records for the survey area during summer, as well as in the Irminger Sea and adjacent waters (OBIS 2023).

#### 3.3.2.13 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).

NAMMCO (2023) reported sightings within the proposed survey area. During a shipboard survey in 1987, sightings were recorded in August near the survey area (Sigurnjónsson et al. 1989). One sighting was made on the Mid-Atlantic Ridge, just south of the survey area, at ~56°N, during June 2004 (Waring et al. 2008). Several sightings have been made during shipboard surveys around Iceland during June–July, including within the survey area (Sigurnjónsson et al. 1985, 1991; Vikingsson et al. 2002; Gunnlaugsson et al. 2004; Pike et al. 2019a). Aerial surveys off western Iceland, north of the survey area, have also reported killer whale sightings during summer (Pike et al. 2008a, 2009a; Gunnlaugsson et al. 2012). Additional sightings have been documented off southwest Iceland, north of the survey area, during May–July by Samarra et al. (2018). Whaling ships reported catches off southwest Iceland, north of survey area, from June to September (Sigurnjónsson and Gunnlaugsson 1990). Sightings of killer whales have also been recorded off southeast Greenland in August and September (Hansen et al. 2018). In the OBIS database, there is one record for the survey area and several records in the waters around Iceland for June–September (OBIS 2023).

#### 3.3.2.14 Harbor porpoise (*Phocoena phocoena*)

The harbor porpoise inhabits cool temperate to subarctic waters of the Northern Hemisphere (Jefferson et al. 2015). Most animals are found over the continental shelf, but some are also encountered over deep water (Westgate et al. 1998). There are likely four populations in the western North Atlantic: Gulf of Maine/Bay of Fundy, Gulf of St. Lawrence, Newfoundland, and Greenland (Gaskin 1984, 1992). Harbor porpoises were detected over the Mid-Atlantic Ridge between ~56° and 57°N between March and September 2012 (Ryan et al. 2013). NAMMCO (2023) reported sightings of harbor porpoise within the proposed survey area, as did Pike et al. (2019a) during shipboard surveys in June–July 2015. Aerial surveys off western Iceland during summer, north of the survey area, also documented harbor porpoise (Pike et al. 2008a, 2009a, 2019b; Gunnlaugsson et al. 2012). Additional sightings have been made off southeast Greenland during August and September (Hansen et al. 2018). In the OBIS database, there are numerous records of harbor porpoise for waters around Iceland, but none within the proposed survey area (OBIS 2023).

### 3.3.3 Pinnipeds

#### 3.3.3.1 Harp Seal (*Pagophilus groenlandicus*)

Harp seals are widespread throughout the Arctic and the northern North Atlantic Ocean (Jefferson et al. 2015). The primary range of harp seals is throughout the Arctic, but its range extends south to the Gulf of Maine (Jefferson et al. 2015). The harp seal's range is tied to the southern and northern extent of the pack ice (Lavigne 2009). The Northwest Atlantic population of harp seals whelps and molts in the Gulf of St. Lawrence and on the ice "Front" off southern Labrador and northeastern Newfoundland from February to May. Most seals migrate north from these areas during April and May to summer in the Arctic, although small numbers remain in southern waters throughout the summer (Stenson and Kavanagh 1994). Boertmann and Rosing-Asvid (2014) reported sightings of harp seals along southeastern Greenland, but there are no records for the survey area in the OBIS database (OBIS 2023).

#### 3.3.3.2 Hooded Seal (*Cystophora cristata*)

The hooded seal is found the Arctic Ocean and in the northern waters of the North Atlantic (Jefferson et al. 2015). Hooded seals breed on pack ice during the spring and shift their distribution with the seasonal changes in ice (Jefferson et al. 2015); they migrate with it as it moves north in the summer and then south in the fall. Three major whelping areas have been identified: Davis Strait; the "West Ice" (west of Jan Mayen Island, off southeastern Greenland); and Canadian waters including the "Front" northeast of Newfoundland, and the Gulf of St. Lawrence (Kovacs 2018). In the western North Atlantic, whelping areas are established by March (Andersen et al. 2009). Hooded seals move slightly northward of their respective breeding areas to molt (Kovacs 2018). After the molt, hooded seals disperse throughout the North Atlantic, and juveniles in particular wander widely (Kovacs 2018). Sightings have been recorded in the Irminger Sea (Andersen et al. 2013) and along the southeast coast of Greenland (Merkel et al. 2010; Boertmann and Rosing-Asvid 2014). However, there are no records of hooded seals in the OBIS database for the proposed survey area (OBIS 2023).

#### 3.3.3.3 Bearded Seal (*Erignathus barbatus*)

Bearded seals are associated with sea ice and have a circumpolar distribution (Burns 1981). They are known to occur along the north coast of Iceland (Reeves et al. 1992), but not the southern coast. During the open-water period, bearded seals occur mainly in relatively shallow areas, because they are predominantly benthic feeders (Burns 1981). Sightings have been recorded off southeastern Greenland (Merkel et al. 2010; Boertmann and Rosing-Asvid 2014), but there are no records for the proposed survey area in the OBIS database (OBIS 2023).

#### 3.3.3.4 Harbor Seal (*Halichoerus grypus*)

The harbor (=common) seal occurs throughout the temperate and subarctic waters of the North Atlantic and North Pacific (Bigg 1981). They are also common along the coasts of Iceland (Thompson et al. 1998a). Harbor seals occur in coastal habitats. The peak in pupping occurs in mid-June at least in the eastern Atlantic (Härkönen and Heide-Jørgensen 1990). Harbor seals forage inshore, usually <50 km from their haul-out sites (see review by Thompson 1993). However, Bjørge et al. (1995) found that some seals forage 50–100 km from shore. There may be small, seasonal shifts in movement of 10–20 km between foraging areas visited during the breading season and those used during winter (Thompson 1989). Bjørge et al. (2002) found that harbor seals tagged on the Norwegian coast dispersed by a mean distance of 69 km; the maximum distance moved was 463 km. Adult harbor seals are relatively sedentary throughout the year, whereas subadults and pups show long range movements (Bonner and Witthames 1974). Sightings are common along the coast of Iceland (Hauksson and Erikson 2010); sightings have also been recorded along southeastern Greenland (Merkel et al. 2010; Boertmann and Rosing-Asvid 2014). Although there are no records of harbor seals in the survey area in the OBIS database, there is one record just to the north at 61.7°N, 27.1°W for June (OBIS 2023).

#### 3.3.3.5 Gray Seal (*Halichoerus grypus*)

The gray seal is found throughout the temperate and subarctic waters of the North Atlantic (King 1983). Generally, gray seals remain over the continental shelf, usually feeding in water <200 m deep (Thompson et al. 1998a). Pupping occurs from September to January (Thompson et al. 1998a). During the breeding season, gray seals show site fidelity for their place of birth (Bjørge et al. 2002). Tagging experiments have shown that gray seals exhibit large-scale movements. Bjørge et al. (2002) found that seals tagged on the Norwegian coast dispersed by a mean distance of 120 km, with a maximum distance of 739 km. Thompson et al. (1998a) noted that seals tagged in the U.K. dispersed as far as 1200 km and that there was an interchange of animals between major haulout areas. One tagged seal was tracked along southeastern Greenland (Boertmann and Rosing-Asvid 2014). There are no records of gray seals for the proposed survey area in the OBIS database, but there is one record for August at 64.2°N, 22.4°W northeast of the survey area, as well as additional sightings to the southeast of the survey area (OBIS 2023).

## 3.4 Sea Turtles

One sea turtle species, the ***endangered*** leatherback sea turtle, could potentially occur near the proposed survey area. Information on the general occurrence near the proposed survey area and conservation status of the leatherback sea turtle is presented in Table 6. General information on the taxonomy, ecology, distribution and movements, and acoustic capabilities of sea turtles are given in § 3.4.1 of the PEIS. The general distribution of sea turtles in the Northwest Atlantic Ocean is discussed in the Northern Atlantic/Iceland Qualitative Analysis Area (QAA) in § 3.4.3 of the PEIS. The rest of this section focuses on their distribution off southern Iceland.

TABLE 6. The habitat, occurrence, and conservation status of sea turtles that could occur in or near the proposed survey area in the North Atlantic Ocean.

| Species | Habitat | Occurrence in Survey Area[1] | US ESA[2] | IUCN[3] | CITES[4] |
|---|---|---|---|---|---|
| Leatherback sea turtle | Beaches (nesting females); oceanic (juveniles and foraging adults) | Rare | E | VU[5] | I |

NL = Not Listed. *Based on professional opinion.

[1] Occurrence in area at the time of the survey; based on professional opinion and available data.

[2] U.S. *Endangered Species Act*: E = Endangered.

[3] International Union for the Conservation of Nature Red List of Threatened Species, version 2022-1: LC = least concern.

[4] Convention on International Trade in Endangered Species: Appendix I, species that are the most endangered and are considered threatened with extinction.

[5] Globally the leatherback is listed as vulnerable by the IUCN, but the Northwest Atlantic Ocean population is listed as endangered.

### 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). The northern extent of its distribution in the North Atlantic is generally restricted to the south of the survey area, spanning from southern Labrador, Canada, to Norway (NOAA 2023a). 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 (Musick and Limpus 1997; Plotkin 2002; Eckert et al. 2012). Adults remain oceanic but many individuals have been shown to be seasonally associated with continental shelves and slopes (Eckert 2006; Doyle et al. 2008; Dodge et al. 2014). Leatherback foraging is affected by the distribution of its gelatinous prey (e.g., James and Herman 2001; Houghton et al. 2006; Hays et al. 2009; Heaslip et al. 2012). No sightings of leatherback sea turtles have been made near the proposed survey area, although it is possible that individuals could be encountered in the offshore survey area. The closest sighting in the OBIS database was reported 600 km to the southeast, at Rockall Bank off the west coast of the U.K. (OBIS 2023). Witt al. (2007) also reported leatherback sea turtles at Rockall Bank during May through October.

## 3.5 Seabirds

Two ESA-listed seabird species could occur in or near the survey area: the ***endangered*** freira, also known as Zino's or Madeira petrel, and the ***endangered*** Bermuda petrel (Table 7). General information on the taxonomy, ecology, distribution and movements, and acoustic capabilities of seabird families are given in § 3.5.1 of the PEIS.

### 3.5.1 Freira (*Pterodroma madeira*)

The Freira's only known breeding sites are six inaccessible ledges on Mt. Areeiro, Madeira (Carboneras et al. 2017). Little is known about their pelagic range, and there have been few confirmed offshore sightings due to their small numbers and close similarity to Fea's petrel (*P. feae*). During the breeding season (April–October), freiras are primarily concentrated near the colony, but small numbers occasionally range as far north as the survey area (see Ramos et al. 2016). During the non-breeding season (November–March), most migrate to tropical Atlantic waters (Ramos et al. 2016).

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

| Species | Occurrence in Survey Area[1] | U.S. ESA[2] | IUCN[3] | CITES[4] |
|---|---|---|---|---|
| Freira | Uncommon | EN | EN | NL |
| Bermuda Petrel | Uncommon | EN | EN | NL |

NL = Not Listed.
[1] Occurrence based on available data and professional opinion. [2] U.S. *Endangered Species Act*; EN = Endangered; T = Threatened. [3] International Union for the Conservation of Nature Red List of Threatened Species, version 2022-2: EN = endangered, LC = least concern. [4] Convention on International Trade in Endangered Species.

### 3.5.2 Bermuda Petrel (*Pterodroma cahow*)

The Bermuda petrel was thought to be extinct by the 17th century until it was rediscovered in 1951, at which time the population consisted of 18 pairs; by 2011, the population had reached 98 nesting pairs (Birdlife International 2023). Currently, all known breeding pairs breed on islets in Castle Harbour, Bermuda (Madeiros et al. 2012). The Bermuda petrel nests from late October through early June (Brinkley and Sutherland 2020). In the non-breeding season (mid-June–mid October), it is thought that birds move west to follow the warm waters on the edge of the Gulf Stream, but a few individuals range off northwestern Europe (Madeiros et al. 2014). Results from geolocator tags showed that individuals have been recorded outside of the Gulf Stream, as far north as the survey area (Madeiros 2009; Maderos et al. 2014; Birdlife International 2023). It surface feeds, securing small fish and cephalopods and other small marine life by sitting on the water and dipping its bill into surface waters. Small numbers of Bermuda petrels could be encountered over the offshore waters of the proposed survey area from June through October.

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

### 3.6.1 Fish and Marine-Invertebrate Species of Conservation Concern

No ESA-listed fish species are expected to occur in occur in the proposed survey area. Although the ***endangered*** European sturgeon may occur in coastal waters of Iceland, it is unlikely to occur in the offshore survey area and is not discussed further. There are no ESA-listed marine invertebrate species in the region. There are currently no petitioned, candidate, or proposed fish or invertebrate species under the ESA that occur near the survey area. Thus, there is no critical habitat for fish species in the proposed survey area.

### 3.6.2 Essential Fish Habitat and Habitat Areas of Particular Concern

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. Habitat Areas of Particular Concern (HAPC) are subsets of EFH that provide important ecological functions and/or are especially vulnerable to degradation and are designated by Fishery Management Councils. There is no EFH or HAPC in the proposed survey area.

# IV ENVIRONMENTAL CONSEQUENCES

## 4.1 Proposed Action

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

The material in this section includes a summary of the expected potential effects (or lack thereof) of airgun sounds on marine mammals and sea turtles given in the PEIS, and reference to recent literature that has become available since the PEIS was released in 2011. A more comprehensive review of the relevant background information appears in § 3.4.4.3, § 3.6.4.3, § 3.7.4.3, § 3.8.4.3, and Appendix E of the PEIS. Relevant background information on the hearing abilities of marine mammals and sea turtles can also be found in the PEIS. This section also includes estimates of the numbers of marine mammals that could be affected by the proposed seismic surveys. A description of the rationale for NSF's estimates of the numbers of individuals exposed to received sound levels ≥160 dB re 1 $\mu Pa_{rms}$ 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, 2019, 2022; Kunc et al. 2016; National Academies of Sciences, Engineering, and Medicine 2017; Weilgart 2017a; Bröker 2019; Rako-Gospić and Picciulin 2019; Burnham 2023). 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 would be 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 were encountered during an active survey, 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, 2020; 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. Kastelein et al. (2023a) reported masking release at various frequencies in harbor seals exposed to noise with fluctuating amplitude. 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) surmised 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.

Southall et al. (2023) proposed data collection and analysis methods to examine the potential effects, including at the population level, of seismic surveys on whales. There have been several 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). Booth et al. (2020) examined monitoring methods for population consequences.

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 $\mu Pa^2 \cdot s$ (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 $\mu Pa^2 \cdot s$ (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). During a seismic survey in Cook Inlet, AK, wide-scale displacement was documented for humpback whales; acoustic detections were reduced or absent during the seismic survey period, but detections increased after the survey finished (Castellote et al. 2020).

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. 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 $\mathrm{CSEL}_{10\text{-min}}$ (cumulative SEL over a 10-min period) of ~94 dB re 1 $\mu\mathrm{Pa}^2 \cdot \mathrm{s}$, decreased at $\mathrm{CSEL}_{10\text{-min}}$ >127 dB re 1 $\mu\mathrm{Pa}^2 \cdot \mathrm{s}$, and whales were nearly silent at $\mathrm{CSEL}_{10\text{-min}}$ >160 dB re 1 $\mu\mathrm{Pa}^2 \cdot \mathrm{s}$. 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 2-week seismic survey, this result was not significant (Muir et al. 2015). However, there may have been a possible localized avoidance response to high sound levels in the area (Muir et al. 2016). The lack of strong avoidance or other strong responses during the 2001 and 2010 programs was presumably in part a result of the comprehensive combination of real-time monitoring and mitigation measures designed to avoid exposing western gray whales to received SPLs above ~163 dB re 1 $\mu\mathrm{Pa}_{\mathrm{rms}}$ (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 short-term and long-term displacement of animals from the feeding area, at least short-term behavioral changes, and responses to lower sound levels than expected (Gailey et al. 2017, 2022a,b; Sychenko et al. 2017). However, stochastic dynamic programming (SDP) model predictions showed similar reproductive success and habitat use by gray whales with or without exposure to airgun sounds during the 2015 program (Schwarz et al. 2022).

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 short-beaked common dolphins were similar during seismic (small or large array) vs. non-seismic operations (Stone 2015). CPA distances for killer whales, white-beaked dolphins, and Atlantic white-sided dolphins were significantly farther (>0.5 km) from large airgun arrays during periods of airgun activity compared with periods of inactivity, with significantly more animals traveling away from the vessel during airgun operation (Stone 2015). Observers’ records suggested that fewer cetaceans were feeding and fewer delphinids were interacting with the survey vessel (e.g., bow-riding) during periods with airguns operating (Stone 2015).

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

Preliminary findings of a monitoring study of *narwhals* in Melville Bay, Greenland, (summer and fall 2012) showed no short-term effects of seismic survey activity on narwhal distribution, abundance, migration timing, and feeding habits (Heide-Jørgensen et al. 2013a). In addition, there were no reported effects on narwhal hunting. These findings do not seemingly support a suggestion by Heide-Jørgensen et al. (2013b) that seismic surveys in Baffin Bay may have delayed the migration timing of narwhals, thereby increasing the risk of narwhals to ice entrapment. 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 of travel at distances up to 24 km from a seismic source; however, 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. Tervo et al. (2023) also noted that narwhals showed increased shallow diving activity and avoided deeper diving, resulting in a reduction in foraging, when exposed to combined ship sounds and airgun pulses. Both studies found that exposure effects could still be detected >40 km from the vessel (Tervo et al. 2021, 2023).

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 would be 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). During a seismic survey in Cook Inlet, AK, wide-scale displacement was documented for harbor porpoises; acoustic detections were reduced or absent during the seismic survey, but detections increased after the survey finished (Castellote et al. 2020).

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 μ$Pa_{0\text{-peak}}$. 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 μ$Pa^2$ · 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. According to Scholik-Schlomer (2015), NMFS is developing new guidance for predicting behavioral effects. 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. 1998b). 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 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). Additional, Nelms et al. (2016) suggest that sea turtles could be excluded from critical habitats during seismic surveys. Green and hawksbill turtles were found to respond to low-frequency sounds (i.e., 0.2–1 kHz upsweeps), but did not respond to impulsive sounds (Kastelein et al. 2023b).

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 μ$Pa_{peak}$. 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 would 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 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, 2023a; 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, 2022a,b; 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 µPa$^2$ · 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). Bottlenose dolphins exposed to 10-ms impulses at 8 kHz with SELs of 182–183 dB re 1 µPa$^2$ · s produced a TTS of up to 35 dB (Mulsow et al. 2023).

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; Mulsow et al. 2023). 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 $\mathrm{SEL_{cum}}$ of 188 and 191 $\mu\mathrm{Pa}^2 \cdot \mathrm{s}$, 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; Finneran et al. 2023b,c).

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 $L_{\mathrm{eq\text{-}fast}}$ (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). Harbour 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 and 4 kHz is similar to that of harbor seals.

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

There is no specific evidence that exposure to pulses of airgun sound can cause PTS in any marine mammal, even with large arrays of airguns. However, given the possibility that some mammals close to an airgun array might incur at least mild TTS, there has been further speculation about the possibility that some individuals occurring very close to airguns might incur PTS (e.g., Richardson et al. 1995, p. 372ff; Gedamke et al. 2011). In terrestrial animals, exposure to sounds sufficiently strong to elicit a large TTS induces physiological and structural changes in the inner ear, and at some high level of sound exposure, these phenomena become non-recoverable (Le Prell 2012). At this level of sound exposure, TTS grades into PTS. Single or occasional occurrences of mild TTS are not indicative of permanent auditory damage, but repeated or (in some cases) single exposures to a level well above that causing TTS onset might elicit PTS (e.g., Kastak and Reichmuth 2007; Kastak et al. 2008).

The 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).

It should be recognized that there are a number of limitations and uncertainties associated with these injury criteria (Southall et al. 2007). Southall et al. (2019) provided updated scientific recommendations regarding noise exposure criteria which are similar to those presented by NMFS (2016a, 2018), but include all marine mammals (including sirenians), and a re-classification of hearing groups. 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. Tougaard et al. (2023) also noted that TTS-onset thresholds for harbor porpoise are likely impacted by the experimental methods used (e.g., behavioral vs. brain stem recordings, and stationary vs. free-swimming animals), in particular for noise exposure >10 kHz.

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. Various authors have reported that sound could be a potential source of stress for marine mammals (e.g., Wright et al. 2011; Atkinson et al. 2015; Houser et al. 2016; Lyamin et al. 2016; Yang et al. 2021). Gray and Van Waerebeek (2011) 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. Williams et al. (2022) reported an increase in energetic cost of diving by narwhals that were exposed to airgun noise, as they showed marked cardiovascular and respiratory reactions.

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., including the currently active UMEs of North Atlantic right whales and Atlantic humpback whales (NOAA 2023b). 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). Based on TTS from exposure to in-air sound, Mannes et al. (2023) surmised that a freshwater turtle would likely exhibit TTS when exposed to SEL of 160 dB re 1 $\mu Pa^2 \cdot s$ for an underwater sound. 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 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 was 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). However, Ruppel et al. (2022) found that MBESs, SBPs, sidescan sonars, ADCPs, and pingers are unlikely to result in take of marine mammals as these sources typically operate at frequencies inaudible to marine mammals, have low source and received levels, narrow beams, downward directed transmission, and/or have low exposure (e.g., short pulse lengths, intermittency of pulses).

There is little information available on marine mammal behavioral responses to MBES sounds (Southall et al. 2013) or sea turtle responses to MBES systems. Much of the literature on marine mammal response to sonars relates to the types of sonars used in naval operations, including low-frequency, mid-frequency, and high-frequency active sonars (see review by Southall et al. 2016). However, the MBES sounds are quite different from naval sonars. Ping duration of the MBES is very short relative to naval sonars. Also, at any given location, an individual marine mammal would be in the beam of the MBES for much less time given the generally downward orientation of the beam and its narrow fore-aft beamwidth; naval sonars often use near-horizontally-directed sound. In addition, naval sonars have higher duty cycles. These factors would all reduce the sound energy received from the MBES relative to that from naval sonars.

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 study 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).

When green and hawksbill sea turtles were exposed to various sounds, they did not respond to impulses or helicopter long range active sonar down-sweeps (Kastelein et al. 2023b). 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 would not be likely to impact marine mammals and would not be expected to affect sea turtles, (1) given the lower acoustic exposures relative to airguns and (2) because the intermittent and/or narrow downward-directed nature of these sounds would result in no more than one or two brief ping exposures of any individual marine mammal or sea turtle given the movement and speed of the vessel. Also, for sea turtles, the associated frequency ranges are above their known hearing range.

#### 4.1.1.3 Other Possible Effects of Seismic Surveys

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

Vessel noise from R/V *Langseth* could affect marine animals in the proposed survey area. Houghton et al. (2015) proposed that vessel speed is the most important predictor of received noise levels, and Putland et al. (2017) also reported reduced sound levels with decreased vessel speed. Sounds produced by large vessels generally dominate ambient noise at frequencies from 20–300 Hz (Richardson et al. 1995). However, some energy is also produced at higher frequencies (Hermannsen et al. 2014; Veirs et al. 2016; 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 behavior (Teilmann et al. 2015; Wisniewska et al. 2018; Tervo et al. 2023), habitat use (e.g., Rako et al. 2013; Carome et al. 2022; Gannier et al. 2022), and swim speeds and movement (e.g., Sprogis et al. 2020; Martin et al. 2022) of cetaceans. Vessel noise has also been shown to affect the dive behavior of pinnipeds (Mikkelsen et al. 2019). 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, 2018; 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. Yurk et al. (2023) suggested that killer whales could avoid masking by using adaptive call design or vocalizing at different frequencies depending on noise levels in their environment.

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 vessels, 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; 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; Bittencourt et al. 2016; Fornet et al. 2018; Laute et al. 2022; Brown et al. 2023; Radtke et al. 2023). Similarly, harbor seals increased the minimum frequency and amplitude of their calls in response to vessel noise (Matthews 2017), and spotted seals increased the source levels of their growls in response to increased ambient noise (Yang et al. 2022). 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. For example, Rolland et al. (2012) 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. 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 area 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). Martin et al. (2023b) reported no long-range (up to 50 km) responses of bowhead whales to passing vessels; responses <8 km from vessels could not be examined. 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 would be 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 (one PSO and one trained observer) maintaining a visual watch during all daytime airgun operations; two PSOs for 30 min before and during ramp ups; PAM during the day and night to complement visual monitoring (unless the system and back-up systems are damaged during operations); shut downs when marine mammals are detected in or about to enter the designated EZ; and shut downs when ESA-listed sea turtles or 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 all 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 Level B Takes by Harassment for Marine Mammals and Sea Turtles

All takes would be anticipated to be Level B "takes by harassment" as described in § I, involving temporary changes in behavior. Further, for this Draft EA, with respect to sea turtles, Level A and Level B are used in the same definition as found in the MMPA and previously issued NMFS Biological Opinion descriptions. 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. (However, as noted earlier and in the PEIS, there is no specific information demonstrating that injurious Level A "takes" would occur even in the absence of the planned mitigation measures.) In the sections below, we describe methods to estimate the number of potential exposures to Level A and Level B sound levels for the high-energy survey, and we present estimates of the numbers of marine mammals and sea turtles 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 southern Iceland in the North Atlantic Ocean.

The numbers of marine mammals that could be exposed to airgun sounds with received levels ≥160 dB re 1 $\mu Pa_{rms}$ (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 seismic tracklines that could be surveyed on one day (~182 km) during MCS surveys and on one day of surveys with OBSs (222 km) that are roughly similar to that of the MCS and OBS surveys regarding the proportion of water depths to be surveyed.

The area expected to be ensonified on a single 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 (9 days for MCS; 5 for OBS). This is equivalent to adding an additional 25% to the proposed line km (Appendix C). 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), as updated in 2022. The habitat-based density models consisted of 5 km x 5 km grid cells. As the AFTT model does not overlap the proposed survey area, the average densities in the grid cells for the AFTT Area that encompassed the same latitudes as the proposed survey area were averaged for each of two water depth categories (intermediate and deep). Due to the location of the proposed survey area and the extrapolation necessary for the modeling for such northern latitudes, densities were the same in intermediate and deep water. Table 8 shows estimated densities for marine mammal species that could occur in the proposed survey area.

For most marine mammal species, only annual densities were available. For some baleen whale species, seasonal densities were available; thus, densities that overlapped the timing of the proposed survey (i.e., summer) were used. For humpback whales, densities are for April to November, and for sei whales, densities are for March to September; densities for North Atlantic right whale were zero for all seasons. Species for which densities were near zero (e.g., false killer whale, melon-headed whale, pygmy killer whale, rough-toothed dolphin, spinner dolphin, Clymene dolphin, Bryde's whale, *Kogia* spp.), as modeled by Roberts et al. (2023), and for which no takes were calculated, were not carried forward through the analysis. Although the modeled density for the pantropical spotted dolphin resulted in a possible single take, this species is unlikely to occur in the proposed survey area, and was also not carried forward. Cuvier's beaked whale was included in the densities for all beaked whales, other than northern bottlenose whales; separate densities were available for northern bottlenose whales. No densities were available for sea turtles. 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.

The estimated numbers of individuals potentially exposed are based on the 160-dB re 1 $\mu\text{Pa}_{\text{rms}}$ criterion for all marine mammals. It is assumed that marine mammals exposed to airgun sounds that strong could change their behavior sufficiently to be considered "taken by harassment". Table 9 shows the estimates of the number of marine mammals that potentially could be exposed to ≥160 dB re 1 $\mu\text{Pa}_{\text{rms}}$ during the proposed seismic surveys if no animals moved away from the survey vessel (see Appendix B for more

TABLE 8. Densities of marine mammals in the proposed survey area south of Iceland, in the North Atlantic Ocean.

| | Density (#/km$^2$) in Survey Area[1] |
|---|---|
| **LF Cetaceans** | |
| North Atlantic right whale | 0 |
| Humpback whale | 1.63E-03 |
| Minke whale | 1.73E-03 |
| Fin whale | 1.69E-03 |
| Sei whale | 2.31E-03 |
| Blue whale | 2.01E-05 |
| **MF Cetaceans** | |
| Sperm whale | 4.26E-03 |
| Cuvier's beaked whale | N.A. |
| Northern bottlenose whale | 4.75E-05 |
| *Mesoplodon* spp. and *Ziphius cavirostris* | 5.08E-03 |
| Blainville's beaked whale | N.A. |
| Sowerby's beaked whale | N.A. |
| Risso's dolphin | 1.82E-02 |
| Atlantic white-sided dolphin | 8.08E-02 |
| Bottlenose dolphin | 1.94E-02 |
| Striped dolphin | 2.95E-03 |
| White-beaked dolphin | 9.21E-04 |
| Common dolphin | 2.68E-01 |
| Globicephala spp. | 2.03E-02 |
| Long-finned pilot whale | N.A. |
| Killer whale | 4.80E-04 |
| **HF Cetaceans** | |
| Harbor porpoise | 2.44E-02 |
| **Phocid Pinnipeds** | |
| Seals | 1.17E-01 |

N.A. = Not available/applicable. [1] Annual densities for marine mammals, except for humpback whale (April-November) and sei whale (March-September) for which densities are seasonal; based on Roberts et al. (2023).

TABLE 9. Estimates of the possible numbers of individual marine mammals that could be exposed to Level B and Level A thresholds for various hearing groups during the proposed seismic surveys south of Iceland, in the North Atlantic Ocean.

| Species | Level B Takes [1] | Level A Takes[2] | % of Pop. (Total Takes)[3] | Requested Level A+B Take Authorization[4] |
|---|---|---|---|---|
| **LF Cetaceans** | | | | |
| Night Atlantic right whale | 0 | 0 | 0 | 0 |
| Humpback whale[5] | 80 | 3 | 1.66 | 83 |
| Minke whale | 84 | 3 | 0.63 | 87 |
| Fin whale | 82 | 3 | 0.73 | 85 |
| Sei whale | 113 | 4 | 0.60 | 117 |
| Blue whale | 1 | 0 | 0.53 | 1 |
| **MF Cetaceans** | | | | |
| Sperm whale | 214 | 0 | 0.33 | 214 |
| Northern bottlenose whale | 2 | 0 | 0.23 | 2 |
| Beaked whales[6] | 255 | 0 | 0.39 | **255** |
| Cuvier's beaked whale | N.A. | N.A. | 4.90 | 229 |
| Blaineville's beaked whale | N.A. | N.A. | 0.43 | 13 |
| Sowerby's beaked whale | N.A. | N.A. | 2.60 | 13 |
| Risso's dolphin | 914 | 2 | 1.17 | 916 |
| Atlantic white-sided dolphin | 4052 | 8 | 2.32 | 4,060 |
| Bottenose dolphin | 974 | 2 | 0.23 | 976 |
| Striped dolphin | 148 | 0 | 0.04 | 148 |
| White-beaked dolphin | 46 | 0 | 1.76 | 46 |
| Common dolphin | 13,443 | 25 | 2.85 | 13,468 |
| Long-finned pilot whales[7] | 1,020 | 2 | 0.39 | 1,022 |
| Killer whale | 24 | 0 | 2.48 | 24 |
| **HF Cetaceans** | | | | |
| Harbor porpoise | 1,181 | 45 | 1.30 | 1,226 |
| **Phocid Seals** | | | | |
| All seals[8] | 5,844 | 35 | 3.92 | **5,879** |
| Hooded seal | N.A. | N.A. | 0.48 | 2,851 |
| Harp seal | N.A. | N.A. | 0.04 | 2,851 |
| Bearded seal | N.A. | N.A. | 0.01 | 59 |
| Gray seal | N.A. | N.A. | 0.21 | 59 |
| Harbor seal | N.A. | N.A. | 0.10 | 59 |

N.A. means not applicable or not available. [1]Level B takes, based on the 160-dB criterion for marine mammals, excluding exposures to sound levels equivalent to PTS thresholds. [2]Level A takes if there were no mitigation measures. [3]Requested take authorization is expressed as % of population for the AFTT Area (Roberts et al. 2023) or North Atlantic (NAMMCO 2023), as applicable, except for beaked whale species and seal species, which are expressed as % population of the Northwest Atlantic based on NOAA (2024) (see Table 5). [4]Requested take authorization is Level A plus Level B calculated takes; takes in bold are for multiple species and have been assigned to several different species within the guild. [5]Based on the best population estimates of 10,752 individuals for the West Indies breeding population (Stevick et al. 2003), and 260 individuals for the Cape Verde breeding population (Ryan et al. 2014); the radio for these two populations was applied to estimate 2 takes for the Cape Verde/Northwest Africa DPS and 81 takes for the West Indies DPS. [6]Most takes (90%) were assigned to the beaked whale species (Cuvier's beaked whale) expected most likely to be encountered in the survey area, with the remainder of takes equally divided between two rare beaked whale species. [7]Takes based on density for *Globicephala* sp. [8]Assumed the two species most likely to be encountered (hooded seal and harp seal) during the survey make up most (~97%) of the takes divided equally between two species; other seals were assigned 1% each of the overall takes.

details), along with the *Requested Take Authorization*. It should be noted that the exposure estimates assume that the proposed surveys would be completed; in fact, the calculated takes for marine mammals ***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; Hückstädt et al. 2020; Hastie et al. 2021; Southall et al. 2021; Booth et al. 2022; 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 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 Tables 2 and 3), if there were no mitigation measures (shut downs when PSOs observe animals approaching or inside the EZs), are also given in Table 9. 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 area.

#### 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 survey; however, following a different methodology than used in the PEIS and most previous analyses for NSF-funded seismic surveys. For recently NSF-funded seismic surveys, NMFS issued small numbers of Level A take for some marine mammal species for the remote possibility of low-level physiological effects; however, NMFS expected neither mortality nor serious injury of marine mammals to result from the surveys (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 (Table 5).

The proposed activities are likely to adversely affect ESA-listed marine mammal species for which takes are being requested (Table 10). However, the relatively short-term exposures are unlikely to result in any long-term negative consequences for the individuals or their populations.

In decades of seismic surveys carried out by R/V *Langseth* and its predecessor, R/V *Ewing*, PSOs and other crew members have seen no seismic sound-related marine mammal injuries or mortality. Also, actual numbers of animals potentially exposed to sound levels sufficient to cause disturbance (i.e., are considered takes) have almost always been much lower than predicted and authorized takes.

For example, during an NSF-funded, ~5000-km, 2-D seismic survey conducted by R/V *Langseth* off the coast of North Carolina in September–October 2014, only 296 cetaceans were observed within the predicted 160-dB zone and potentially taken, representing <2% of the 15,498 takes authorized by NMFS (RPS 2015). During an USGS-funded, ~2700 km, 2-D seismic survey conducted by R/V *Langseth* along the U.S. east coast in August–September 2014, only 3 unidentified dolphins were observed within the predicted 160-dB zone and potentially taken, representing <0.03% of the 11,367 authorized takes (RPS 2014b). Furthermore, as defined, all animals exposed to sound levels >160 dB are Level B 'takes' whether or not a behavioral response occurred. The Level B estimates are thought to be conservative; thus, not all animals detected within this threshold distance would be expected to have been exposed to actual sound levels >160 dB.

***Sea Turtles*.—**In § 3.4.7, the PEIS concluded that with implementation of the proposed monitoring and mitigation measures, no significant impacts of airgun operations are likely to sea turtle populations in any of the analysis areas, and that any effects are likely to be limited to short-term behavioral disturbance and short-term localized avoidance of an area of unknown size near the active airguns. In decades of seismic surveys carried out by R/V *Langseth* and its predecessor, R/V *Ewing*, PSOs and other crew members have seen no seismic sound-related sea turtle injuries or mortality. The proposed activities are unlikely to adversely affect ESA-listed sea turtles as leatherback turtle densities in the proposed survey area are expected to be near zero, and this species is unlikely to be encountered (Table 11).

### 4.1.2 Direct Effects on Marine Invertebrates, Fish, 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, 2021; Carroll et al. 2017; Hawkins and Popper 2017; Popper and Hawkins 2019; Wale et al. 2021; Hawkins 2022a,b; Popper et al. 2022; Solé et al. 2023; Vereide and Kühn 2023), 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; McCauley et al. 2021). 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). 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).

TABLE 10. ESA determination for marine mammal species that could be encountered during the proposed surveys south of Iceland, in the North Atlantic Ocean.

| | ESA Determination | | |
|---|---|---|---|
| **Species** | **No Effect** | **May Affect – Not Likely to Adversely Affect** | **May Affect – Likely to Adversely Affect** |
| North Atlantic Right Whale | √ | | |
| Humpback Whale (Cape Verde/Northwest Africa DPS ) | | | √ |
| Sei Whale | | | √ |
| Fin Whale | | | √ |
| Blue Whale | | | √ |
| Sperm Whale | | | √ |

TABLE 11. ESA determination for sea turtle species that could be encountered during the proposed surveys south of Iceland, in the North Atlantic Ocean.

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

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 mollusks, 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, 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; Hawkins 2022a; Solé et al. 2023; Vereide and Kühn 2023) 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.

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.

Vereide et al. (2023) conducted a field experiment that examined the effects of a seismic survey on the mortality and development of nauplii of the copepod *Acartia tonsa*. The nauplii were held in plastic bags that were suspended at a depth of 6 m; these were exposed at a distance of 50 m for 2.5 hours to discharges from two 40-in3 airguns towed behind a vessel. Controls of the experiment included periods with vessel noise only (no airguns), as well as silence. After exposure, the nauplii were brought to the laboratory where greater immediate mortality (14%) was observed in the nauplii exposed to airgun sounds compared with those during the vessel only and silent controls. After 4 days, most of the exposed nauplii were dead, whereas most nauplii in the control groups were still alive 6 days after exposure. Exposed nauplii also had lower growth rates than those that were not exposed to airgun sounds.

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.

Parsons et al. (2023) conducted a large-scale experiment at a pearl oyster holding lease site to examine the effect of a seismic survey on mortality and productivity of silverlip pearl oysters (*Pinctada maxima*). The oysters were exposed to four days of seismic survey sounds using a 2600 $in^3$ airgun array with a peak to peak source level of 252 dB re 1 µPa at 1 m and a sound exposure level of 228 dB re 1 $Pa^2m^2s$; the experiment also included one vessel-control day. The oysters were monitored for a full two-year production cycle. Only two of 16 groups showed reduced survival and pearl productivity; thus, the study found no conclusive evidence that the commercial important oyster was impacted by the seismic survey sounds.

Hubert et al. (2022a) examined the response of wild-caught blue mussels to exposures of single pulses and pulse trains in an aquarium. They reported that the mussels responded to the sounds by partially closing their valves and that the response waned with repeated exposures. They could not determine whether the decay in response was due to habituation or a sensory adaptation. There was no difference in recovery time between exposures to single pulses or a pulse trains. Hubert et al. (2022b) noted that the sound-induced valve closure varied with pulse train speed – mussels exposed to faster pulse trains returned to baseline conditions faster than those exposed to slower pulse trains; phytoplankton clearance rates were not impacted.

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). Day et al. (2019, 2021, 2022) exposed rock lobster to the equivalent of a full-scale commercial seismic survey passing within 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 distance range showed recovery, whereas those exposed at closer range had persistent impairment (Day et al. 2019, 2021, 2022). Day et al. (2021, 2022) noted that there was indication for slowed growth and physiological stress in 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 haemolymph parameter that was significantly affected by airgun exposure was the Brix index of haemolymph at 120 and 365 days post-airgun exposure in one of the experiments involving egg-laden females. Other studies conducted in the field have shown no effects on Dungeness crab (*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 $\mu Pa_{rms}$ 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 $\mu Pa_{rms}$, 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 $SPL_{0-p}$ of 251 dB re 1 µPa, and SEL of 229 dB re 1 $\mu Pa^2 \cdot s$ (the same seismic source as used by Morris et al. 2018, noted below). The movements of the 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).

In total, 201 and 115 snow crab were tagged in Carson and Lilly canyons, respectively. Before, During, and After exposure periods to a single 2D seismic surveying line (5–8 hours 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 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." There was also no evidence of physical damage to internal organs based on histological examinations (Morris et al. 2021). The study 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 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).

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 2 h and sampled before, and 18 h 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 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. 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.

Roberts and Laidre (2019) studied the effect of an impulsive sound source on the chemically mediated shell searching behavior of the hermit crab (*Pagarus acadianus*). Although the sound source was not seismic airgun-related, it was impulsive. An underwater slide hammer was used to create vibration within the seabed, allowing the production of a fully controllable manually operated stimulus. Exposures consisted of repetitive low-frequency pulses, with most energy within the 500–700 Hz range. The average peak particle velocity ranges at 1-m and 5-m were 0.00001–0.0005 m/s and 0.00002–0.00009 m/s, respectively. Results of this study indicated the sound source used can act cross-modally and affect chemically guided search behavior. The broad conclusion was that anthropogenic noise and seabed vibration may have effects on other behaviors mediated by other sensory modalities.

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

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.

Buscaino et al. (2019) exposed caged sea urchins (*Arbacia lixula*) and sea cucumbers (*Holothuria tubulosa*) to sounds from an airgun with a peak pressure level of 122 dB re 1 $\mu Pa^2/Hz$ at 850 Hz and a peak particle speed of 207 dB re $(1\ nm/s)^2$ at 550 Hz. When the coelemic fluid was extracted from each animal (40 individuals of each species), there was evidence of stress as indicated by differences in esterase and peroxidase in sea urchins and total hemocyte count and total protein for the sea cucumbers.

Spiga (2022) reported behavioral responses of snapping shrimp in the field to playbacks of impulses with frequencies of 50–600 Hz when exposed to sound pressure levels at or above to 130 re 1 µPa and particle motion of $2.06 \times 10^{-06}$ m/s. Bigger shrimp snapped more for longer durations and moved away from the sound source; peak frequency of snaps decreased during exposure compared with before and after sound exposure.

#### 4.1.2.2 Effects of Sound on Fish

Popper et al. (2019a) and Popper and Hawkins (2021) 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), Slabbekoorn et al. (2019), and Hawkins (2022a,b), and Lessa (2023); they include pathological, physiological, and behavioral effects. Radford et al. (2014), Putland et al. (2017), de Jong et al. (2020), Pine et al. (2020), and Jones et al. (2023) 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.

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 North west 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.

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 $\mu Pa^2 \cdot s$. Wei and McCauley (2022) determined that the angle of sound energy arrival at the otolith (a pathway for sound transmittance between a sound source and the inner ear) affects the extent of potential injury from noise. de Jong et al. (2020) conducted a study on the predicted effects of anthropogenic noise on fish reproduction and found that continuous sounds with irregular amplitudes and/or frequency-content such as heavy ship traffic were likely to induce masking or hearing loss. The vulnerability of a species to noise-induced stressors was dependent on its ability to reallocate reproduction to a quieter location or time, and whether or not their reproductive strategy relied on sound communication. Although TTS has been demonstrated in some fish species, it is unlikely to occur in free-swimming fish (Smith and Popper 2023).

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 $\mu Pa^2 \cdot s$. Although cod had a reduced hear rate in response to the sound exposure, there was no behavioral startle response. However, 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. Davidsen et al. (2019) concluded that the sound exposures over a 3-day period were unlikely to lead to long-term alterations in physiology or behavior.

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 µPa$^2$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 during 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; they exhibited more transiting behavior (i.e., swimming at high speed with a low turning angle) during and after exposure. Similar results were obtained during an experiment that exposed wild-caught Atlantic cod to airgun playbacks in an experimental tank with an SPL of 150 dB re 1 µPa$_{0\text{-}p}$; although the cod did not change the time spent foraging, they did increase the time spent swimming during exposure (Hubert et al. 2019; Hubert 2021).

When McQueen et al. (2022, 2023) exposed Atlantic cod on their spawning grounds to airgun sounds with received exposure levels of 115 to 145 dB re 1 µPa$^2$s, the fish showed weak responses by swimming slightly deeper during sound exposure; however, they did not change their swimming acceleration nor were they displaced from the exposed area. According to McQueen et al. (2023), the results suggest that distant seismic surveys 5 to >40 km away would not significantly change cod behaviour (McQueen et al. 2023).

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 µPa$^2 \cdot$ 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.

Neo et al. (2014, 2015, 2016, 2018) reported changes in fish (primarily European seabass) behavior (e.g., dive depth, group cohesion, swim speed) upon exposure to impulsive sounds and noted that temporal structure of sound plays a large role in the potential response of fish to noise exposure. Neo et al. (2014) also postulated that intermittent sounds, such as from airguns, may elicit a stronger response by fish than continuous sounds, regardless of the cumulative sound exposure level.

Waddell and Širović (2023) examined larval fish behaviour in a linear acoustic chamber when exposed to airgun sounds. They found that larvae of drum (*Sciaenops ocellatus*), southern flounder (*Paralichthys lethostigma*), and spotted seatrout (*Cynoscion nebulosus*) actively avoided airguns sounds, but habituated to the noise within 10 min.

Sivle et al. (2017) examined the behavioural responses of wild captured mackerel in a net pen to sounds from a 90 $\text{in}^3$ airgun towed behind a vessel; SELs ranged from 146 to 171 re 1 $\mu\text{Pa}_{0\text{-p}}$. No overt responses (e.g., changes in swimming dynamics, swim speed, etc.) were recorded during sound exposure. When fish were exposed to airgun sounds at close range (90 m) at received SPLs of 184 dB re 1 $\mu\text{Pa}_{0\text{-p}}$, they swam rapidly. This suggests that the threshold between subtle reactions and avoidance responses occurs between 178 and 184 dB re 1 $\mu\text{Pa}_{0\text{-p}}$, and that ramp up of sound may be effective at minimizing initial responses to sound.

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 231 dB re 1 µPa. Results of the study indicated no mortality, either during or seven days after exposure, and no statistical differences in effects on body tissues between exposed and control fish.

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

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

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 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 fish.

Kok et al. (2021) examined the behavior of pelagic fish to seismic surveys using echosounders; the received SPLs at the echosounder ranged from 123 to 195 dB re 1 $\mu Pa_{0-p}$. They found that there were fewer schools of fish during the seismic surveys, but the schools were more cohesive than before the sound exposure.

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 and no post-seismic evaluation was possible, it contributes evidence that normal fish use of reef ecosystems is reduced when they are impacted by seismic sounds.

#### 4.1.2.3 Conclusions for Invertebrates and Fish

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. PSOs would also watch for any impacts the acoustic sources may have on fish during the survey. Given the proposed activities, impacts would not be anticipated to be significant or likely to adversely affect (including ESA-listed) marine invertebrates or marine fish. 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.

### 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 $\mu Pa_{rms}$ (Hansen et al. 2017). Gentoo penguins, black ducks, and great cormorants have been found to be able to detect underwater sounds (e.g., Hansen et al. 2017, 2020, 2023; Larsen et al. 2020; Sørensen et al. 2020; McGrew et al. 2022; Rasmussen et al. 2022). Great cormorants may have special adaptations for hearing underwater (Johansen et al. 2016; Hansen et al. 2017).

Common murres (*Uria aalge*) were found to respond negatively to pulsed sound (Hansen et al. 2020). 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 shut down in the event an ESA-listed seabird was observed diving or foraging within the designated EZ.

However, ESA-listed seabirds that could be present forage at the ocean surface rather than diving and would not be affected by the airgun operations below the water surface. Thus, given the proposed activities, types of ESA species and behaviors, avoidance measures and unlikelihood of encounter, no effects to ESA-listed seabirds would be anticipated from the proposed action (Table 12). In decades of seismic surveys carried out by R/V *Langseth* and its predecessor, the R/V *Ewing*, PSOs and other crew members have seen no seismic sound-related seabird injuries or mortality.

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

The proposed seismic operations would not result in any permanent impact on habitats used by marine mammals, sea turtles, seabirds, 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 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 proposed survey 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) and Lonsdale et al. (2020) proposed practical management steps to limit cumulative impacts, including new procedures for assessing cumulative impacts from human activity on the marine environment, and minimizing exposure by reducing exposure rates and levels. The results of the cumulative impacts analysis in the PEIS indicated that there would not be any significant cumulative effects to marine resources from the proposed NSF-funded marine seismic research, including the combined use of airguns with MBES, SBP, and acoustic pingers.

However, the PEIS also stated that, "A more detailed, cruise-specific cumulative effects analysis would be conducted at the time of the preparation of the cruise-specific EAs, allowing for the identification of other potential activities in the areas of the proposed seismic surveys that may result in cumulative impacts to environmental resources." Here we focus on activities (e.g., research, vessel traffic, and fisheries) that could impact animals specifically in the proposed survey area. 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.

TABLE 12. ESA determination for seabird species that could be encountered during the proposed surveys south of Iceland, in the North Atlantic Ocean.

| | ESA Determination | | |
|---|---|---|---|
| **Species** | **No Effect** | **May Affect – Not Likely to Adversely Affect** | **May Affect – Likely to Adversely Affect** |
| Freira | √ | | |
| Bermuda petrel | √ | | |

#### 4.1.5.1 Past and Future Research Activities

The Reykjanes Ridge is an area of significant interest due to its unique geophysical features. Various types of seismic surveys have occurred in the area dating back to the 1970s. Seismic surveys have been conducted by several research teams over various years in the area to image the crust and upper-most mantle structure (e.g., Jacoby et al. 2007). The Reykjanes Ridge is also commonly studied for its volcanism and tectonics; these studies aim to understand the process of oceanic crust formation. For example, Le Saout et al. (2023) used remotely operated vehicles deployed from research vessels to record video footage of the ocean floor. Other scientific seismic research activities and other studies may be conducted in this region in the future. However, at the present time, the proponents of the proposed survey are not aware of other marine research activities planned to occur in the proposed survey area during 2024.

#### 4.1.5.2 Whaling

In Iceland, whales are directly harvested by Icelandic commercial and scientific whaling (Ahmed et al. 2020). From 1986 and 2018, at least 1796 whales (1073 fin whales, 653 minke whales, and 70 sei whales) were harvested by Icelandic commercial and scientific whaling (Ahmed 2020). However, sei whales have not been harvested since 1989 (Ahmed 2020), and minke whales have not been taken since 2019 (Statistics Iceland 2023). No whales were harvested during 2019–2021, but 148 fin whales were taken in 2022 (Statistics Iceland 2023). A total of 14,340 t of whale products were exported from Iceland during 2008–2022 (Statistics Iceland 2023).

Due to concerns from the Icelandic Food and Veterinary Authority and the Animal Welfare Advisory Board, the 2023 whaling season was postponed until September 1, 2023 (Ministry of Food, Agriculture and Fisheries 2023); so far in 2023, 24 fin whales have been harvested (Statistics Iceland 2023). Whaling regulations will be created to include detailed requirements for whaling equipment and methods; the Food and Veterinary Authority along with the Directorate of Fisheries will be tasked with supervising the whale hunt and summarizing their findings at the end of the 2023 season (Ministry of Food, Agriculture and Fisheries 2023).

#### 4.1.5.3 Entanglements

The primary contributions of fishing to potential cumulative impacts on marine mammals, sea turtles, and seabirds involve direct removal of prey items, noise, and potential entanglement (Reeves et al. 2003). The commercial fisheries in the region are described in § III. There may also be some localized avoidance by marine mammals of fishing vessels near the proposed seismic survey area.

***Marine mammals*.—**In Icelandic waters, humpback whales are likely the most frequently entangled among the large whale species (Basran and Rassmussen 2021). Humpback interactions with capelin purse seines in nearshore waters are concentrated in the north, northeast, and southwest of Iceland where this fishery overlaps humpback feeding areas (Basran and Rassmussen 2021). Other whales that have been reported to interact with fishing gear in Iceland including killer whales, sperm whales, blue whales, and minke whales (Basran and Rassmussen 2021). Gillnet fisheries in nearshore waters for lumpfish were estimated to bycatch a total of 3570 marine mammals between 2014 to 2017, including an estimated 1385 gray seals, 1367 harbor seals, 551 harbor porpoise, 177 harp seals, 53 ringed seals, and 36 bearded seals (MFRI 2018). In 2020, the bycatch estimate for harbor porpoises was 1713, and for gray seals it was 760 (Taylor et al. 2022).

***Seabird*.**—Entanglement in fishing gear and hooking can also lead to mortality of seabirds. Part of the sustainability movement in Iceland includes maintaining a Marine Stewardship Council (MSC) certification. This certification status currently depends on decreasing incidence of seabird bycatch by the lumpfish fishery. This is being done in partnership with the Royal Society for the Protection of Birds (RSPB), through innovative technologies meant to deter seabirds from landing in areas where gillnets are in use (MSC 2023). The gillnet fishery has been estimated to kill over 8000 seabirds in Iceland each year (Amaral-Rodgers 2023). Other common species affected include common eiders, black guillemots, great cormorants, European shags, and long-tailed ducks; most of the affected species are listed as endangered or vulnerable on the Icelandic Red List for birds (Amaral-Rogers 2023).

***Sea Turtles*.**—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 industry 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 area, which is very low. 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.

#### 4.1.5.4 Fisheries

Commercial fisheries data are collected by the Food and Agriculture Organization (FAO), including commercial group, gear type, and landing mass, all of which are reported by the state of landing (Sea Around Us 2016). Fisheries data from 2015–2019, the last year with available data, are summarized below for non-EEZ waters of the Northeast Atlantic (i.e., Northeast Atlantic High Seas). For 2015–2019, the commercial landings for non-EEZ waters of the Northeast Atlantic averaged 460,576 t, with a value of $1140.5 million (Sea Around Us 2016). In 2019, commercial catches for the region totaled 734,940 t (Sea Around Us 2016). The average annual catch weights and gear types for major commercial groups are summarized in Table 13. Typical commercial fishing vessels in the area include pelagic trawlers, bottom trawlers, longliners, purse seiners, and gill netters.

Interactions between the proposed surveys and fishing operations in the survey area are expected to be limited. Two possible conflicts in general are R/V *Langseth*'s streamer entangling with fishing gear and the temporary displacement of fishers from the survey area. Fishing activities could occur within the proposed survey area; a safe distance would need to be kept from R/V *Langseth* and the towed seismic equipment. Conflicts would be avoided through Notice to Mariners and communication with the fishing community during the surveys.

TABLE 13. Average commercial fishery landings during 2015–2019 for fish groups for non-EEZ waters of the Northeast Atlantic by weight and gear type.

| Commercial Group | Average Annual Catch (t) | Percentage of Total Catch (%) | Gear Types |
|---|---|---|---|
| Cod-like fishes, including Atlantic cod | 29,714 | 6.45 | bottom trawl, longline, gillnet, dredge, purse seine, pelagic trawl, shrimp trawl, hand lines, Small-scale pots and traps |
| Crustaceans | 3,082 | 0.67 | bottom trawl, gillnet, dredge, shrimp trawl |
| Flatfishes | 282 | 0.06 | bottom trawl, gillnet, dredge, purse seine, longline, hand lines, small scale pots or traps, shrimp trawl, |
| Herring-like fishes | 34 | 0.01 | bottom trawl, purse seine, gillnet, pelagic trawl, |
| Molluscs | 20 | ~0 | bottom trawl, gillnet dredge, longline, purse seine |
| Other fishes and invertebrates, including blue whiting and Atlantic mackerel | 416,692 | 90.47 | bottom trawl, longline, gillnet, pelagic trawl, purse seine, shrimp trawl, handline, artisanal fishing gear, small-scale encircling nets, small-scale pots or traps, small-scale trammel net, pole and line, |
| Perch-like fishes | 418 | 0.09 | bottom trawl, longline, purse seine, gillnet, dredge, shrimp trawl, pelagic trawl |
| Salmon, smelts, etc. | 84 | 0.02 | Purse seine |
| Scorpionfishes | 32 | 0.01 | bottom trawl, gillnet, dredge, purse seine, longline |
| Sharks and rays, including blue shark | 6,048 | 1.31 | bottom trawl, longline, purse seine, dredge, gillnet, pole and line, handlines, pots or traps |
| Tuna and billfishes, including swordfish and albacore tuna | 4,170 | 0.91 | longline, bottom trawl, purse seine, gillnet, pole and line, handlines, pots and traps |
| **Total** | **460,576** | **100** | |

Source: Sea Around US (2016)

### 4.1.5.5 Vessel Traffic

Reykjavik is a major port for marine traffic, with vessels transiting through the Irminger Basin and the Iceland Basin. Based on data available through the Automated Mutual-Assistance Vessel Rescue (AMVER) system managed by the U.S. Coast Guard (USCG), typically fewer than four vessels per month transit the survey area (USCG 2023). Various types of vessels occurred within the proposed survey area when MarineTraffic (2023) was accessed on 27 September 2023, including cargo vessels (19), tankers (4), fishing vessels (3), a tug, and a special craft. The total distance that would be traveled by R/V *Langseth* (~3200 km) would be relatively small compared with the total transit lengths for vessels operating in the proposed survey area at the time of the survey. Thus, the projected increases in vessel traffic attributable to implementation of the proposed activities would constitute only a negligible portion of the total existing vessel traffic in the analysis area, and only a negligible increase in overall ship disturbance effects on marine mammals. Although collisions of vessels with marine mammals have been reported for the Northeast Atlantic Ocean, the risk for a collision between whales and ships are largest closer to shore around Iceland, and there is a relatively low risk around the proposed survey area (EEA 2021).

### 4.1.6 Unavoidable Impacts

Unavoidable impacts to the species of marine mammals and sea turtles occurring in the proposed survey area would be limited to short-term, localized changes in behavior of individuals. For marine mammals, some of the changes in behavior may be considered to fall within the MMPA definition of "Level B Harassment" (behavioral disturbance; no serious injury or mortality). TTS, if it occurs, would be limited to a few individuals, is a temporary phenomenon that does not involve injury, and is unlikely to have long term consequences for the few individuals involved. No long-term or significant impacts would be expected on any of these individual marine mammals or 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.

### 4.1.7 Coordination with Other Agencies and Processes

This Draft EA has been prepared by LGL on behalf of L-DEO and NSF pursuant to Executive Order 12114. Potential impacts to marine mammals, endangered species, and critical habitat have also been assessed in the document; therefore, it will be used to support the ESA Section 7 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, the University of Birmingham, University of Southampton, and University of Cambridge, to NMFS, under the U.S. MMPA, for "taking by harassment" (disturbance) of small numbers of marine mammals, for the proposed seismic surveys.

## 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. Geological data of scientific value that would shed light on some of the most remarkable perturbations to global climate, ecosystems, and the carbon cycle in Earth's history, 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. The No Action Alternative would not meet the purpose and need for the proposed activity.

# V LIST OF PREPARERS

**LGL Ltd., environmental research associates**

Caralee Baker, B.Sc., St. John’s, NL
Meike Holst, M.Sc., Sidney, BC*
Darren Ireland, M.Sc., Bozeman, MT
Colin Jones, B.Sc., St. John’s, NL
W. John Richardson, Ph.D., King City, ON
Chirathi Wijekulathilake, M.Sc., St. John’s, NL

**Lamont-Doherty Earth Observatory**

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

**National Science Foundation**

Holly E. Smith, M.A., Alexandria, 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.

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# LIST OF APPENDICES

## APPENDIX A: DETERMINATION OF MITIGATION ZONES

## APPENDIX B: MARINE MAMMAL TAKE CALCULATIONS

## APPENDIX C: ENSONIFIED AREA CALCULATIONS

# APPENDIX A: DETERMINATION OF MITIGATION ZONES

# APPENDIX A: DETERMINATION OF MITIGATION ZONES

During the planning phase, mitigation zones for the proposed marine seismic surveys were calculated based on modeling by L-DEO for Level A and Level B (160 dB re 1µPa$_{rms}$) thresholds. 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. 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 surveys would acquire data with the 36-airgun array at a maximum tow depth of 12 m. 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 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 $1 \mu Pa_{rms}$ sound levels are expected to be received for the 36-airgun array. 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 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-2) 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 $1 \mu Pa_{rms}$, 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. 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.

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[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).

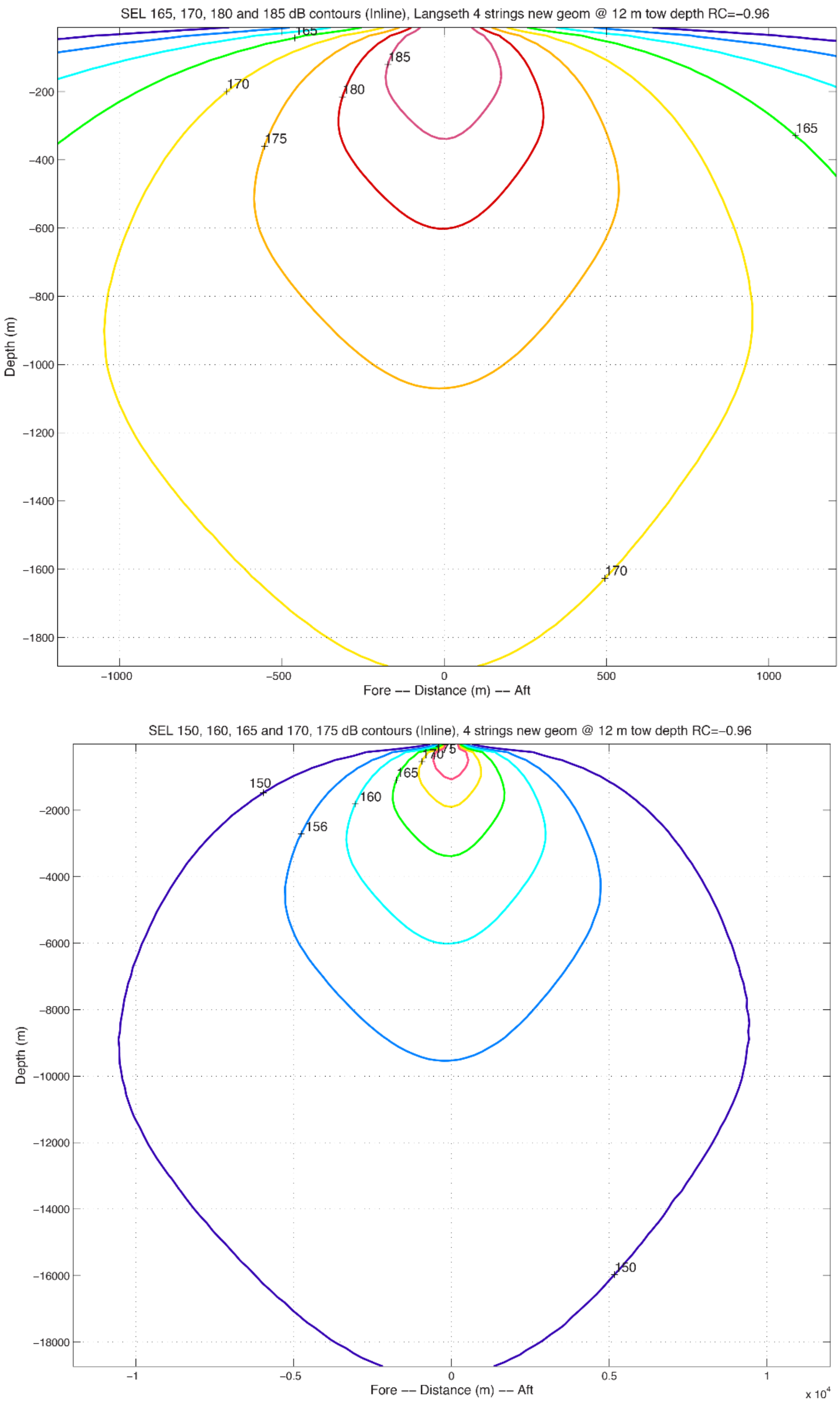


FIGURE A-1. Modeled deep-water received sound exposure levels (SELs) from the 36-airgun array at a 12-m tow depth planned for use during the proposed surveys. Received rms levels (SPLs) are expected to be ~10 dB higher. For example, the radius to the 150-dB SEL isopleth is a proxy for the 160-dB rms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

TABLE A-1. Predicted distances to behavioral disturbance sound levels ≥160-dB re 1 μPa$_{rms}$ and ≥175-dB re 1 μPa$_{rms}$ that could be received during the proposed surveys south of Iceland, in the North Atlantic Ocean. The 160-dB criterion applies to all hearing groups of marine mammals (Level B harassment), and the 175-dB criterion applies to sea turtles.

| Source and Volume | Tow Depth[1] (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 |
|---|---|---|---|---|
| 4 strings, 36 airguns, 6600 in$^3$ | 12 | >1000 m | 6,733[2] | 1,864[2] |
| | | 100–1000 m | 10,100[3] | 2,796[3] |

[1] Maximum tow depth was used for conservative distances. [2] Distance is based on L-DEO model results. [3] Distance is based on L-DEO model results with a 1.5 × correction factor between deep and intermediate water depths.

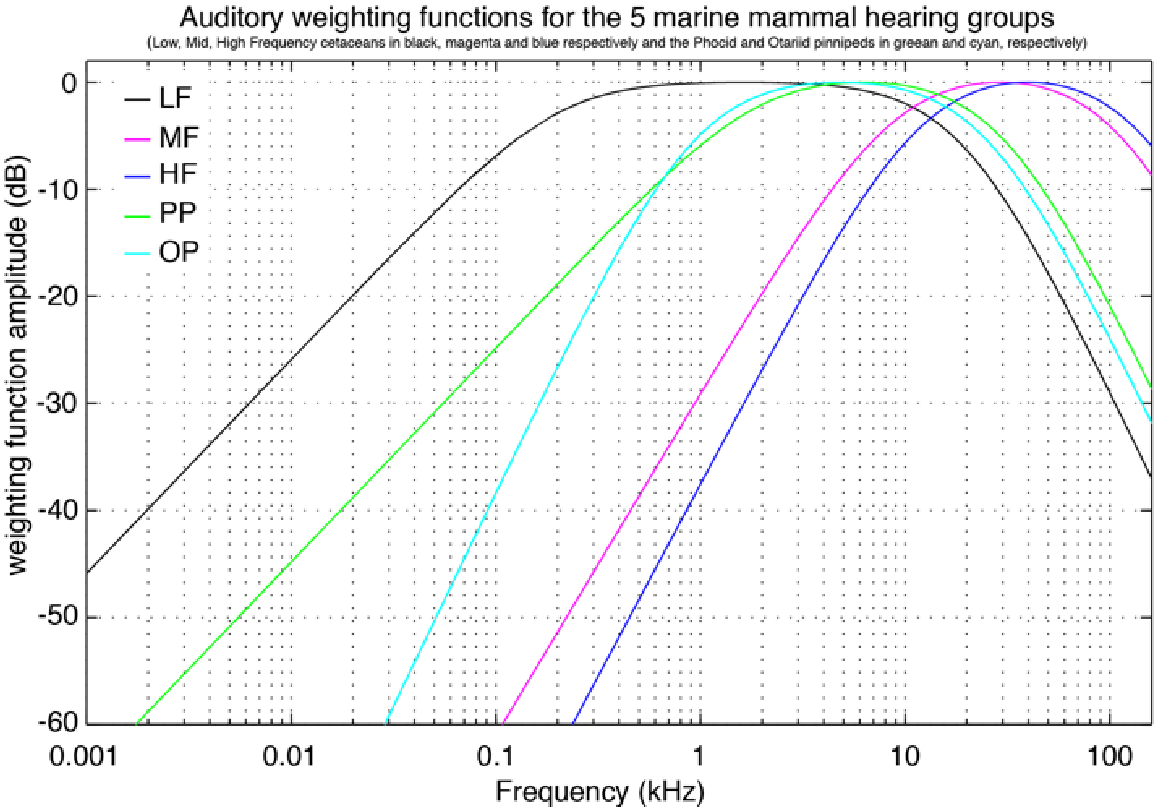


FIGURE A-2. Auditory weighting functions for five marine mammal hearing groups from the NMFS Technical Guidance Spreadsheet.

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.

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 $\text{SEL}_{\text{cum}}$ 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** | **204*** |
|---|---|---|---|---|---|---|
| **Radial Distance (m) (no weighting function)** | 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 $\text{SEL}_{\text{cum}}$, and the distances to the PTS thresholds for the 36-airgun array are shown in Table A-3. Figure A-3 shows the impact of weighting functions by hearing group. Figures A-4–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.

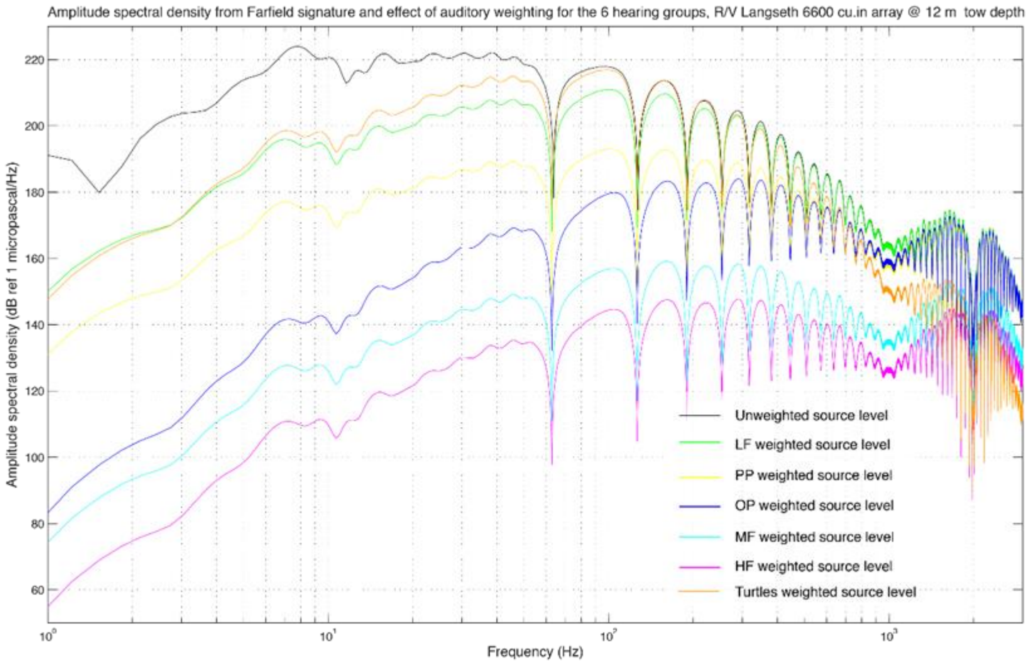
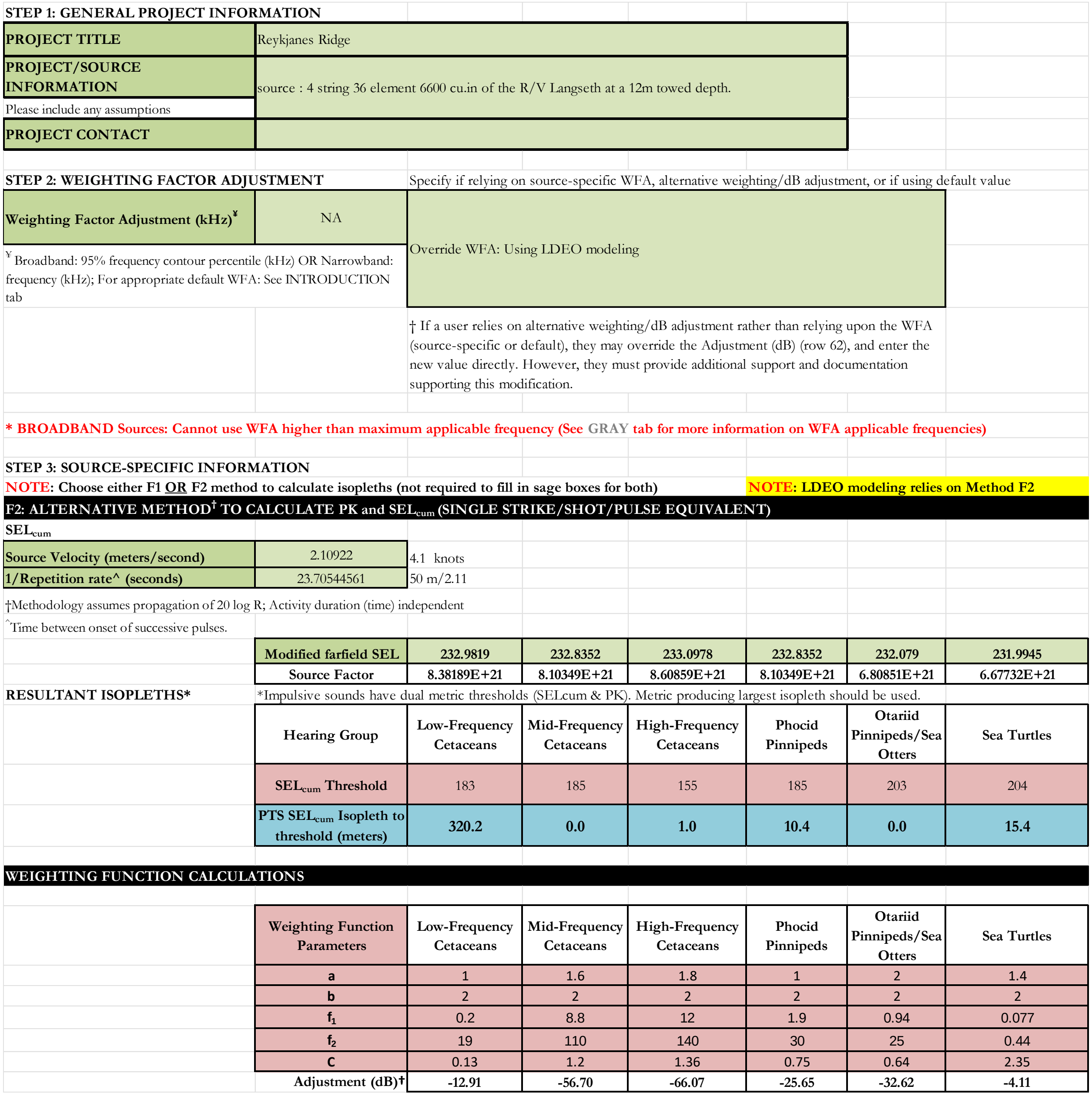


FIGURE A-3. Modeled amplitude spectral density of the 36-airgun array farfield signature. Amplitude spectral density before (black) and after (colors) applying the auditory weighting functions for LF, MF, and HF cetaceans, Phocid Pinnipeds (PP), and Otariid Pinnipeds (OP). Modeled spectral levels are 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, for the MCS surveys.



**STEP 1: GENERAL PROJECT INFORMATION**

| | |
|---|---|
| **PROJECT TITLE** | Reykjanes Ridge |
| **PROJECT/SOURCE INFORMATION**<br>Please include any assumptions | source : 4 string 36 element 6600 cu.in of the R/V Langseth at a 12m towed depth. |
| **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)** | 2.10922 | 4.1 knots |
| **1/Repetition rate^ (seconds)** | 23.70544561 | 50 m/2.11 |

†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** | **8.38189E+21** | **8.10349E+21** | **8.60859E+21** | **8.10349E+21** | **6.80851E+21** | **6.67732E+21** |

**RESULTANT ISOPLETHS***

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

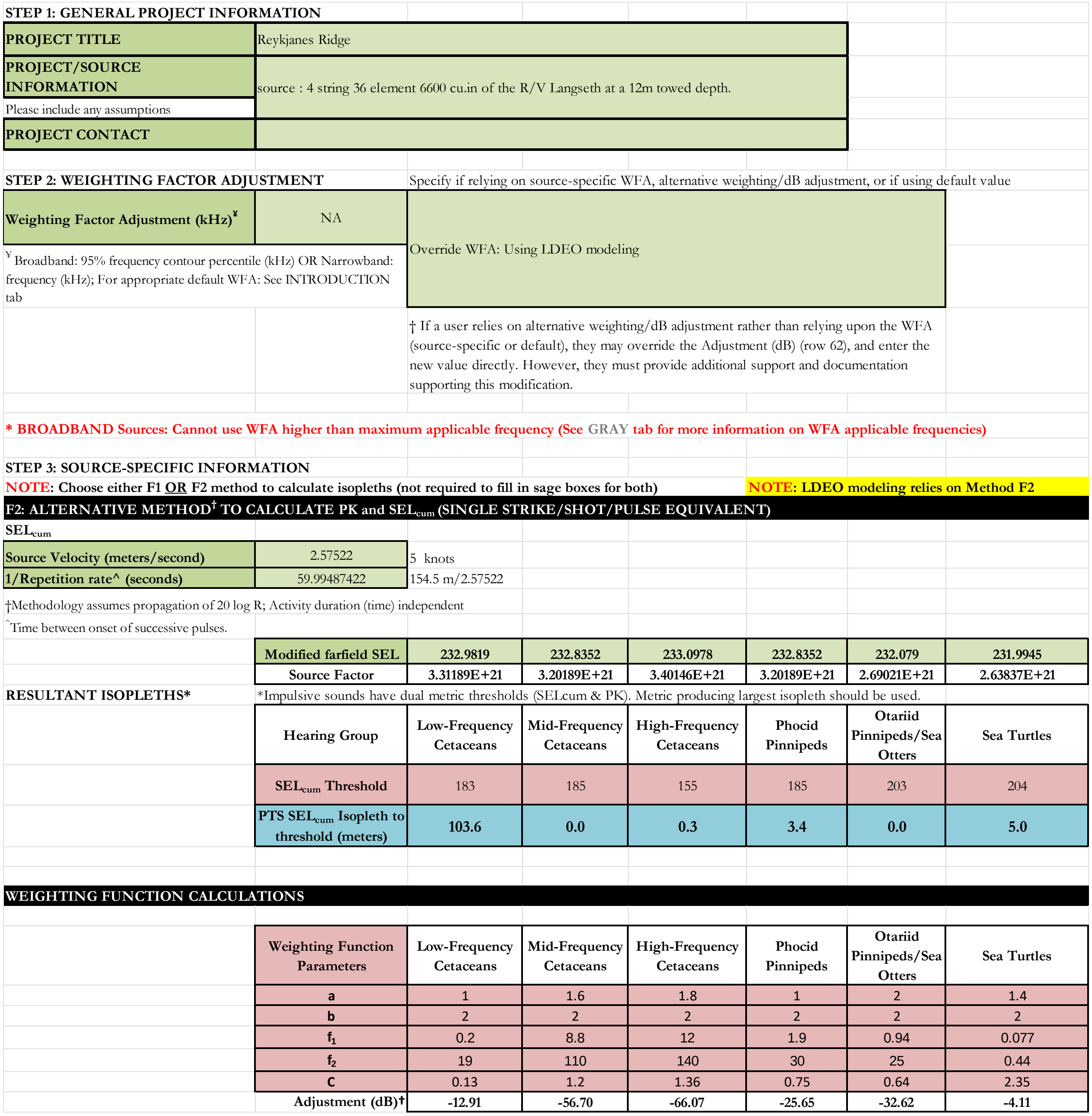
| Hearing Group | Low-Frequency Cetaceans | Mid-Frequency Cetaceans | High-Frequency Cetaceans | Phocid Pinnipeds | Otariid Pinnipeds/Sea Otters | Sea Turtles |
|---|---|---|---|---|---|---|
| **$SEL_{cum}$ Threshold** | 183 | 185 | 155 | 185 | 203 | 204 |
| **PTS $SEL_{cum}$ Isopleth to threshold (meters)** | **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 |

†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-3).

TABLE A-4. Results for single shot SEL source level modeling for the 36-airgun array with weighting function calculations for the $\text{SEL}_{\text{cum}}$ criteria, as well as resulting isopleths to thresholds for various hearing groups, for the OBS surveys.



**STEP 1: GENERAL PROJECT INFORMATION**

| | |
|---|---|
| **PROJECT TITLE** | Reykjanes Ridge |
| **PROJECT/SOURCE INFORMATION**<br>Please include any assumptions | source : 4 string 36 element 6600 cu.in of the R/V Langseth at a 12m towed depth. |
| **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 $\text{SEL}_{\text{cum}}$ (SINGLE STRIKE/SHOT/PULSE EQUIVALENT)**

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

| | | |
|---|---|---|
| **Source Velocity (meters/second)** | 2.57522 | 5 knots |
| **1/Repetition rate^ (seconds)** | 59.99487422 | 154.5 m/2.57522 |

†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** | **3.31189E+21** | **3.20189E+21** | **3.40146E+21** | **3.20189E+21** | **2.69021E+21** | **2.63837E+21** |

**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** | **Sea Turtles** |
|---|---|---|---|---|---|---|
| **$\text{SEL}_{\text{cum}}$ Threshold** | 183 | 185 | 155 | 185 | 203 | 204 |
| **PTS $\text{SEL}_{\text{cum}}$ Isopleth to threshold (meters)** | **103.6** | **0.0** | **0.3** | **3.4** | **0.0** | **5.0** |

**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** |

†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-3).

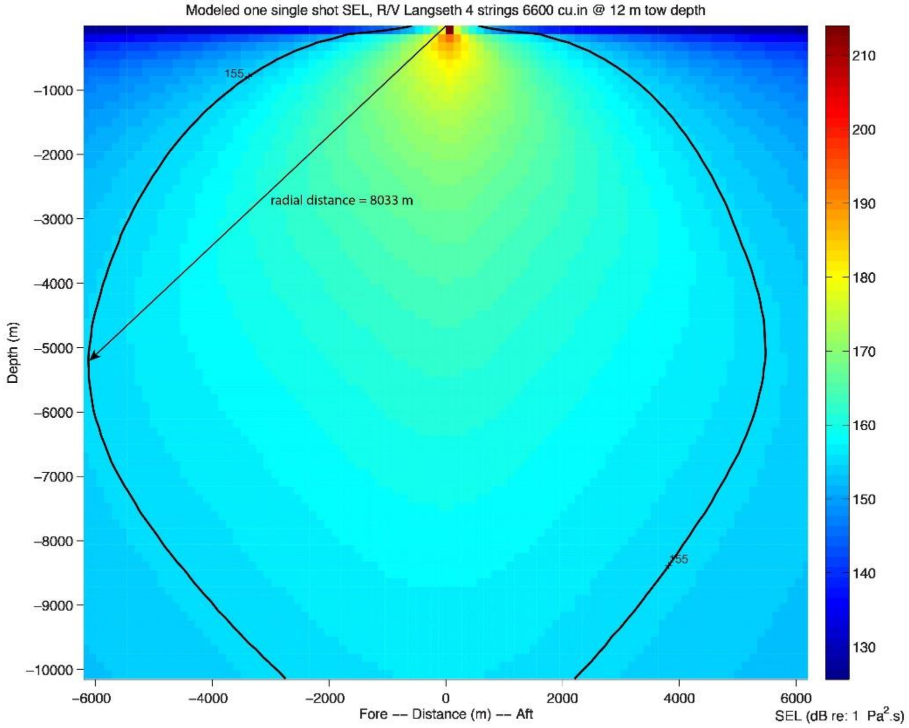


FIGURE A-4. Modeled received sound levels (SELs) in deep water from the 36-airgun array. The plot provides the radial distance from the geometrical center of the source array to the 155-dB SEL isopleth (8033 m). Radial distance allows us to determine the modified farfield SEL using a propagation of 20log$_{10}$(radial distance).

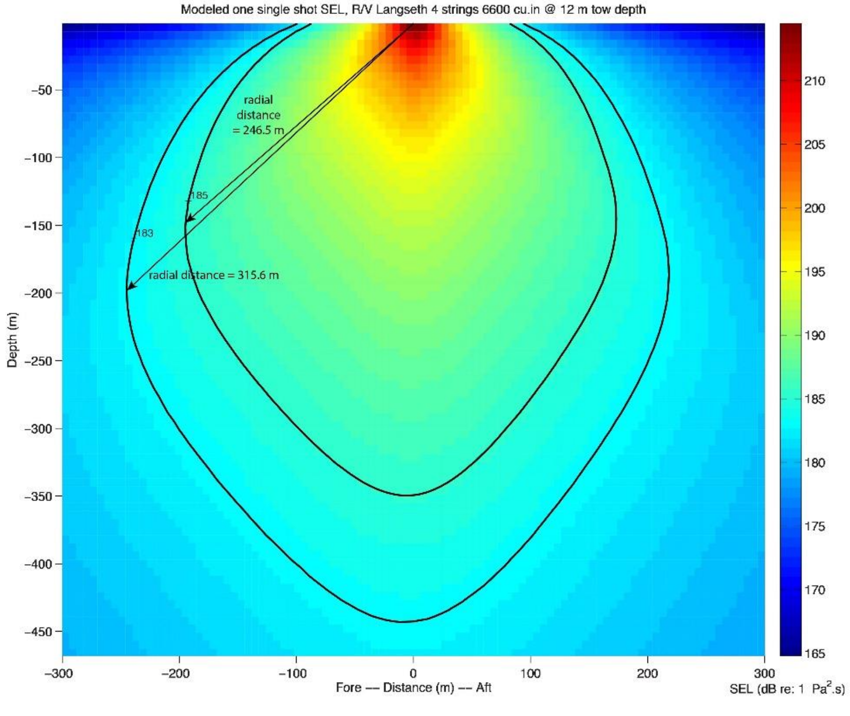


FIGURE A-5. Modeled received sound levels (SELs) in deep water from the 36-airgun array. The plot provides the radial distance from the geometrical center of the source array to the 183–185-dB SEL isopleths (315.6 and 246.5 m, respectively).

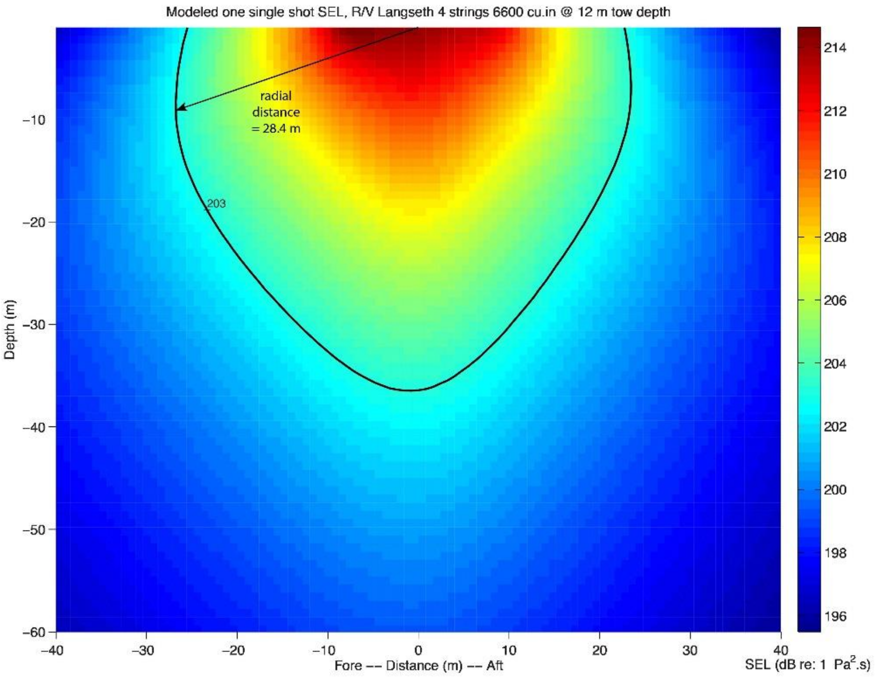


FIGURE A-6. Modeled received sound levels (SELs) in deep water from the 36-airgun array. The plot provides the radial distance from the geometrical center of the source array to the 203-dB SEL isopleth (28.4 m).

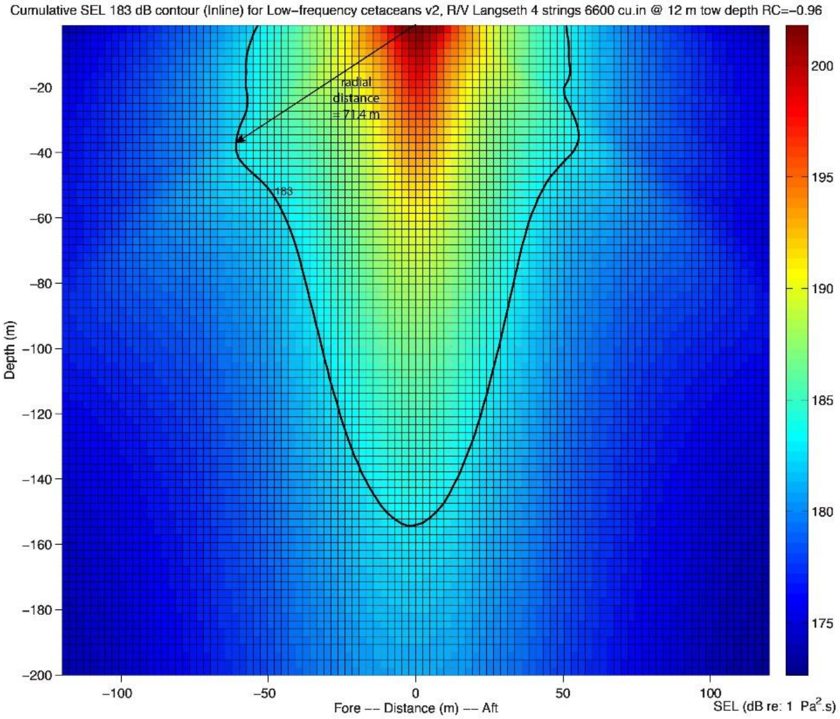


FIGURE A-7. Modeled received sound exposure levels (SELs) from the 36-airgun array at a 12-m tow depth, after applying the auditory weighting function for the LF cetaceans hearing group following the NMFS Technical Guidance. The plot provides the radial distance to the 183-dB $SEL_{cum}$ isopleth for one shot. The difference in radial distances between Fig. A-5 and this figure (71.4 m) allows us to estimate the adjustment in dB.

The thresholds for Peak $SPL_{flat}$ for the 36-airgun array, as well as the distances to the PTS thresholds, are shown in Table A-5. Figures A-8–A-10 show the modeled received sound levels to the Peak $SPL_{flat}$ thresholds, for a single shot. A summary of the Level A threshold distances are shown in Table A-6.

TABLE A-5. 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 hearing groups that could be received from the 36-airgun array during the proposed surveys.

| 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-6. 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 ($SEL_{cum}$ 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 |
| ***MCS Surveys*** |  |  |  |  |  |  |
| 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 |
| ***OBS Surveys*** |  |  |  |  |  |  |
| PTS $SEL_{cum}$ | **103.6** | 0 | 0.3 | 3.4 | 0 | 5.0 |
| PTS Peak | 38.9 | **13.6** | **268.3** | **43.7** | **10.6** | **10.6** |

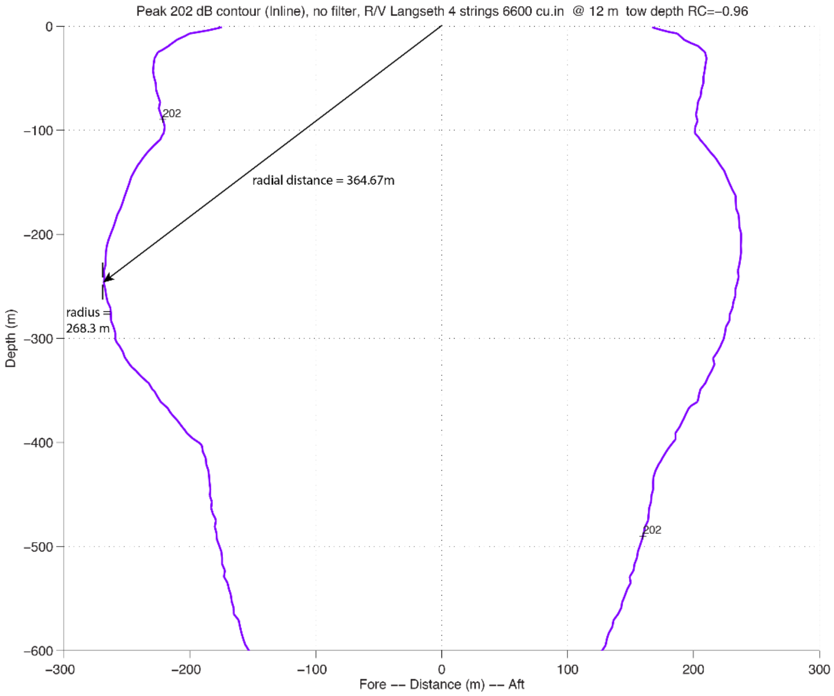


FIGURE A-8. Modeled deep-water received Peak SPL from the 36-airgun array at a 12-m tow depth. The plot provides the distance to the 202-dB Peak isopleth.

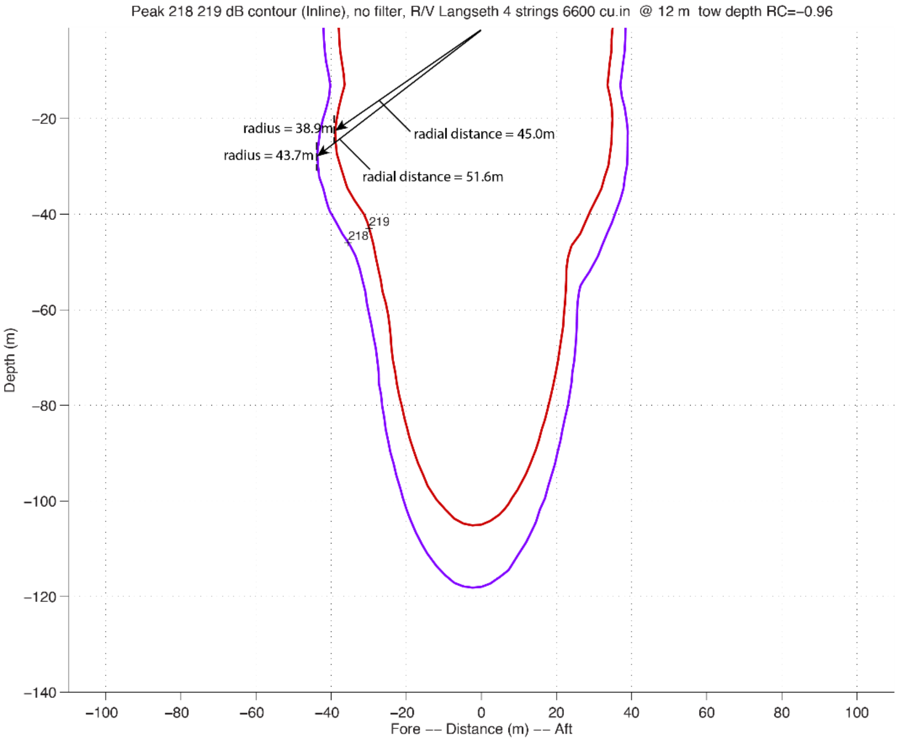


FIGURE A-9. Modeled deep-water received Peak SPL from the 36-airgun array at a 12-m tow depth. The plot provides the distances to the 218- and 219-dB Peak isopleths.

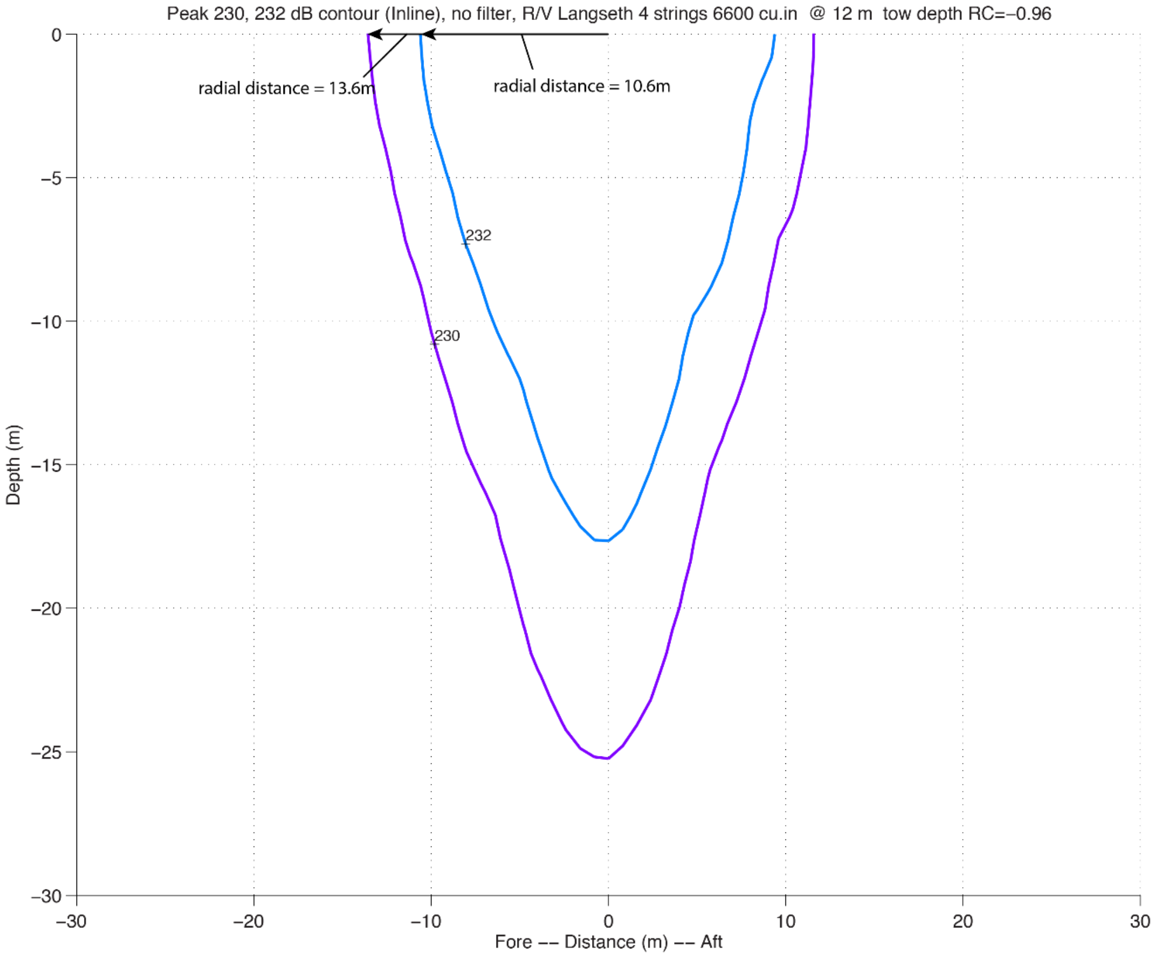


FIGURE A-10. Modeled deep-water received Peak SPL from the 36-airgun array at a 12-m tow depth. The plot provides the distances to the 230- and 232-dB Peak isopleths.

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# APPENDIX B: MARINE MAMMAL TAKE CALCULATIONS

# APPENDIX B: MARINE MAMMAL TAKE CALCULATIONS

Level A and Level B takes were determined for the seismic surveys; the detailed take calculations are shown in Table B-1. The ensonified areas that were used to calculate Level A and B takes are provided in Appendix C.

TABLE B-1. Take estimates for the proposed surveys south of Iceland, in the North Atlantic Ocean.

| Species | Estimated Density (#/km$^2$) | Population Size for Western North Atlantic | Population Size for AFTT Area | Hearing Group | Level B Ensonified Area (km$^2$) | Level A Ensonified Area (km$^2$) | All Takes | Only Level B Takes minus Level A[1] | Level A Takes[2] | % of Pop. (Total Takes)[3] | Requested Level A+B Take Authorization[4] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **LF Cetaceans** | | | | | | | | | | | |
| Night Atlantic right whale | 0 | 340 | 711 | LF | 50,261 | 1,603 | 0 | 0 | 0 | 0 | 0 |
| Humpback whale[5] | 0.0016342 | 1,396 | 4,990 | LF | 50,261 | 1,603 | 83 | 80 | 3 | 1.66 | 83 |
| Minke whale | 0.0017283 | 21,968 | 13,784 | LF | 50,261 | 1,603 | 87 | 84 | 3 | 0.63 | 87 |
| Fin whale | 0.0016925 | 6,802 | 11,672 | LF | 50,261 | 1,603 | 85 | 82 | 3 | 0.73 | 85 |
| Sei whale | 0.0023141 | 6,292 | 19,530 | LF | 50,261 | 1,603 | 117 | 113 | 4 | 0.60 | 117 |
| Blue whale | 0.0000201 | 402 | 191 | LF | 50,261 | 1,603 | 1 | 1 | 0 | 0.53 | 1 |
| **MF Cetaceans** | | | | | | | | | | | |
| Sperm whale | 0.0042599 | 5,895 | 64,015 | MF | 50,261 | 93 | 214 | 214 | 0 | 0.33 | 214 |
| Northern bottlenose whale | 0.0000475 | 19,500 | 1,056 | MF | 50,261 | 93 | 2 | 2 | 0 | 0.23 | 2 |
| Beaked whales[6] | 0.0050812 | N.A. | 65,069 | MF | 50,261 | 93 | 255 | 255 | 0 | 0.39 | **255** |
| Cuvier's beaked whale | N.A. | 4,670 | N.A. | MF | 50,261 | 93 | N.A. | N.A. | N.A. | 4.90 | 229 |
| Blaineville's beaked whale | N.A. | 2,936 | N.A. | MF | 50,261 | 93 | N.A. | N.A. | N.A. | 0.43 | 13 |
| Sowerby's beaked whale | N.A. | 492 | N.A. | MF | 50,261 | 93 | N.A. | N.A. | N.A. | 2.60 | 13 |
| Risso's dolphin | 0.0182267 | 44,067 | 78,205 | MF | 50,261 | 93 | 916 | 914 | 2 | 1.17 | 916 |
| Atlantic white-sided dolphin | 0.0807748 | 93,233 | 175,299 | MF | 50,261 | 93 | 4,060 | 4052 | 8 | 2.32 | 4,060 |
| Bottenose dolphin | 0.0194155 | 64,587 | 418,151 | MF | 50,261 | 93 | 976 | 974 | 2 | 0.23 | 976 |
| Striped dolphin | 0.0029469 | 48,274 | 412,729 | MF | 50,261 | 93 | 148 | 148 | 0 | 0.04 | 148 |
| White-beaked dolphin | 0.0009208 | 536,016 | 2,627 | MF | 50,261 | 93 | 46 | 46 | 0 | 1.76 | 46 |
| Common dolphin | 0.2679635 | 93,100 | 473,260 | MF | 50,261 | 93 | 13,468 | 13,443 | 25 | 2.85 | 13,468 |
| Long-finned pilot whales[7] | 0.0203314 | 39,215 | 264,907 | MF | 50,261 | 93 | 1,022 | 1,020 | 2 | 0.39 | 1,022 |
| Killer whale | 0.0004801 | 15,000 | 972 | MF | 50,261 | 93 | 24 | 24 | 0 | 2.48 | 24 |
| **HF Cetaceans** | | | | | | | | | | | |
| Harbor porpoise | 0.0243892 | 85,765 | 94,583 | HF | 50,261 | 1,847 | 1,226 | 1,181 | 45 | 1.30 | 1,226 |
| **Phocid Seals** | | | | | | | | | | | |
| All seals[8] | 0.1169634 | N.A. | 150,075 | P | 50,261 | 300 | 5,879 | 5,844 | 35 | 3.92 | **5,879** |
| Hooded seal | N.A. | 600,000 | N.A. | P | 50,261 | 300 | N.A. | N.A. | N.A. | 0.48 | 2,851 |
| Harp seal | N.A. | 7,600,000 | N.A. | P | 50,261 | 300 | N.A. | N.A. | N.A. | 0.04 | 2,851 |
| Bearded seal | N.A. | 500,000 | N.A. | P | 50,261 | 300 | N.A. | N.A. | N.A. | 0.01 | 59 |
| Gray seal | N.A. | 27,911 | N.A. | P | 50,261 | 300 | N.A. | N.A. | N.A. | 0.21 | 59 |
| Harbor seal | N.A. | 61,336 | N.A. | P | 50,261 | 300 | N.A. | N.A. | N.A. | 0.10 | 59 |

N.A. means not applicable or not available. [1]Level B takes, based on the 160-dB criterion for marine mammals, excluding exposures to sound levels equivalent to PTS thresholds. [2]Level A takes if there were no mitigation measures. [3]Requested take authorization is expressed as % of population for the AFTT Area (Roberts et al. 2023), except for beaked whale species and seal species, which are expressed as % population of the Northwest Atlantic based on NOAA (2024) (see Table 5). [4]Requested take authorization is Level A plus Level B calculated takes; takes in bold are for multiple species and have been assigned to several different species within the guild. [5]Based on the best population estimates of 10,752 individuals for the West Indies breeding population (Stevick et al. 2003), and 260 individuals for the Cape Verde breeding population (Ryan et al. 2014); the radio for these two populations was applied to estimate 2 takes for the Cape Verde/Northwest Africa DPS and 81 takes for the West Indies DPS. [6]Most takes (90%) were assigned to the beaked whale species (Cuvier's beaked whale) expected most likely to be encountered in the survey area, with the remainder of takes equally divided between two rare beaked whale species. [7]Takes based on density for *Globicephala* sp. [8]Assumed the two species most likely to be encountered (hooded seal and harp seal) during the survey make up most (~97%) of the takes divided equally between two species; other seals were assigned 1% each of the overall takes.

# APPENDIX C: ENSONIFIED AREA CALCULATIONS

# APPENDIX C: ENSONIFIED AREA CALCULATIONS

The ensonified areas that were used to calculate Level A and B takes for the proposed surveys south of Iceland, in the North Atlantic Ocean.

Table C-1. Areas expected to ensonified during the proposed surveys.

| | Survey Zone | Criterion | Daily Ensonified Area (km$^2$) | Total Survey Days | 25% Increase | Total Ensonified Area (km$^2$) | Relevant Isopleth (m) |
|---|---|---|---|---|---|---|---|
| **Marine Mammals** | | | | | | | |
| MCS | Int 100-1000 m | 160 dB | 590.1 | 9 | 1.25 | 6638.8 | 10,100 |
| MCS | Deep >1000 m | 160 dB | 2082.5 | 9 | 1.25 | 23428.3 | 6,733 |
| OBS | Int 100-1000 m | 160 dB | 720.0 | 5 | 1.25 | 4500.2 | 10,100 |
| OBS | Deep >1000 m | 160 dB | 2511.1 | 5 | 1.25 | 15694.1 | 6,733 |
| | **Overall** | **160 dB** | **5903.7** | **14** | **1.25** | **50261.4** | |
| **Hearing Groups** | | | | | | | |
| MCS | All zones | LF Cetacean | 116.9 | 9 | 1.25 | 1314.8 | 381.1 |
| MCS | All zones | MF Cetacean | 5.0 | 9 | 1.25 | 55.7 | 13.6 |
| MCS | All zones | HF Cetacean | 97.9 | 9 | 1.25 | 1101.2 | 268.3 |
| MCS | All zones | Phocid Pinniped | 15.9 | 9 | 1.25 | 179.0 | 43.7 |
| OBS | All zones | LF Cetacean | 46.0 | 5 | 1.25 | 287.7 | 103.9 |
| OBS | All zones | MF Cetacean | 6.0 | 5 | 1.25 | 37.7 | 13.6 |
| OBS | All zones | HF Cetacean | 119.4 | 5 | 1.25 | 745.9 | 268.3 |
| OBS | All zones | Phocid Pinniped | 19.4 | 5 | 1.25 | 121.3 | 43.7 |

Note: Ensonified areas are adjusted for overlap and include endcaps.