Draft Environmental Assessment/Analysis of Marine Geophysical Surveys by R/V *Sikuliaq* in the Arctic Ocean, Summer 2021

Prepared for

University of Alaska Geophysics Institute
900 Yukon Drive
Fairbanks, AK 99775

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

12 February 2021

LGL Report FA0221-A

TABLE OF CONTENTS

LIST OF FIGURES

Page

LIST OF TABLES

Page

ABSTRACT

Researchers from the University of Alaska Geophysics Institute, with funding from the U.S. National Science Foundation (NSF), and in collaboration with researchers from the Geological Survey of Denmark and Greenland, propose to conduct low- and high-energy seismic surveys from the Research Vessel (R/V) *Sikuliaq* in the Arctic Ocean during summer 2021. The NSF-owned R/V *Sikuliaq* is operated by the College of Fisheries and Ocean Sciences at University of Alaska Fairbanks under an existing Cooperative Agreement. A small portion of the proposed seismic survey activity would occur within the Exclusive Economic Zones (EEZ) of the U.S.; most of the survey activity would be conducted in International Waters. The surveys would use a towed array of two or six 520 in^3 G-airguns with a maximum total discharge volume of ~3120 in^3 and would occur in water depths ranging from 200 to 4000 m.

NSF, as the research funding and action agency, has a mission to "promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense…". The proposed seismic surveys would collect data in support of a research proposal that has been reviewed under the NSF merit review process and identified as an NSF program priority. They would provide data necessary to map the northern edge in the Chukchi Borderland and the adjacent Canada Basin.

This Draft Environmental Assessment/Analysis (EA) addresses NSF's requirements under the National Environmental Policy Act (NEPA) for the proposed NSF federal action within the U.S. EEZ and Executive Order 12114, "Environmental Effects Abroad of Major Federal Actions", for the proposed NSF federal action in International Waters. As operator of R/V *Sikuliaq*, the University of Alaska, on behalf of itself and NSF, have requested an Incidental Harassment Authorization (IHA) from the U.S. National Marine Fisheries Service (NMFS) and U.S. Fish and Wildlife Service (USFWS) 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 seabirds, fish, and invertebrates. As analysis on endangered and threatened species was included, this document will also be used to support Endangered Species Act (ESA) Section 7 consultations with NMFS and U.S. Fish and Wildlife Service (USFWS). Alternatives addressed in this EA consist of the Proposed Action with issuance of an associated IHA and the No Action alternative, with no IHA and no seismic surveys. This document tiers to the Programmatic Environmental Impact Statement/Overseas Environmental Impact Statement for Marine Seismic Research Funded by the National Science Foundation or Conducted by the U.S. Geological Survey (June 2011) and Record of Decision (June 2012), referred to herein as PEIS.

Numerous species of marine mammals could occur in or near the proposed project area in the Arctic Ocean. Under the U.S. ESA, several of these species are listed as ***endangered***, including the bowhead whale, fin whale, Western North Pacific Distinct Population Segment (DPS) of gray whale, and Western North Pacific DPS of humpback whale. The ***threatened*** polar bear, Mexico DPS of humpback whale, Beringia DPS of the Pacific bearded seal, and Arctic subspecies of ringed seal could also occur in or near the survey area. The polar bear and walrus are marine mammal species mentioned in this document that, in the U.S., are managed by the USFWS; all others are managed by NMFS.

Although Alaskan fish populations are not listed under the ESA, there are several ESA-listed fish species that spawn on the west coast of the Lower 48 U.S. that could occur in Alaskan waters during the marine phases of their life cycles, including several ***endangered*** and ***threatened*** evolutionary significant units (ESUs) of chinook, chum, coho, and sockeye salmon. In addition, the ***threatened*** Steller's and

spectacled eiders, and the ***endangered*** short-tailed albatross could occur in the wider region, but are unlikely to occur within the proposed project area.

Potential impacts of the proposed seismic surveys on the environment would be primarily a result of the operation of the airgun array. A multibeam echosounder and sub-bottom profiler would also be operated during the surveys. Impacts from the Proposed Action would be associated with increased underwater anthropogenic sounds, which could result in avoidance behavior by marine mammals, 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 and seabirds have not been proven to occur near airgun arrays or the other types of sound sources to be used. However, a precautionary approach would be taken, and the planned monitoring and mitigation measures would reduce the possibility of any effects.

Protection measures designed to mitigate the potential environmental impacts to marine mammals and seabirds would include the following: ramp ups; typically two (but a minimum of one) dedicated observers maintaining a visual watch during all daytime airgun operations; two observers before and during ramp ups during the day; start-ups during poor visibility or at night if the exclusion zone (EZ) has been acoustically monitored (e.g., passive acoustic monitoring or PAM) for 30 minutes with no detections; PAM via towed hydrophones during both day and night to complement visual monitoring; and shut downs when marine mammals are detected in or about to enter designated EZ. Observers would also watch for impacts the acoustic sources may have on fish. The University of Alaska and its contractors are committed to applying these measures in order to minimize effects on marine mammals, seabirds, and fish, and other potential environmental impacts. Survey operations would be conducted in accordance with all applicable international, U.S. federal, and state regulations, including IHA and Incidental Take Statement (ITS) requirements.

With the planned monitoring and mitigation measures, unavoidable impacts to each species of marine mammal that could be encountered would be expected to be limited to short-term, localized changes in behavior and distribution near the seismic vessel. At most, effects on marine mammals would be anticipated as falling within the Marine Mammal Protection Act (MMPA) definition of "Level B Harassment" for those species managed by NMFS. No long-term or significant effects would be expected on individual marine mammals, seabirds, fish, the populations to which they belong, or their habitats. NSF followed the 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
ACP	Alaska Coastal Plain
ADCP	Acoustic Doppler Current Profiler
ADF&G	Alaska Department of Fish and Game
AEP	Auditory Evoked Potential
AEWC	Alaska Eskimo Whaling Commission
AMOS	Arctic Mobile Observing System
AMVER	Automated Mutual-Assistance Vessel Rescue
ASAMM	Aerial Survey of Arctic Marine Mammals
BCB	Bering-Chukchi-Beaufort
BIA	Biologically Important Area
CAATEX	Coordinated Arctic Active Tomography Experiment
CBD	Convention on Biological Diversity
CITES	Convention on International Trade in Endangered Species
COMIDA	Chukchi Offshore Monitoring in Drilling Area
CTD	Conductivity Temperature Depth
DAA	Detailed Analysis Area
dB	decibel
DPS	Distinct Population Segment
EA	Environmental Assessment/Analysis
EBSA	Ecologically or Biologically Significant Marine Areas
EFH	Essential Fish Habitat
EIS	Environmental Impact Statement
EO	Executive Order
ESA	(U.S.) Endangered Species Act
ESU	Evolutionary Significant Units
EZ	Exclusion Zone
FM	Frequency Modulated
FMP	Fishery Management Plan
FONSI	Finding of no significant impact
GIS	Geographic Information System
GOA	Gulf of Alaska
GOM	Gulf of Mexico
h	hour
HAPC	Habitat Area of Particular Concern
hp	horsepower
Hz	Hertz
ICEXs	Ice Exercises
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
MBES	Multibeam Echosounder
MCS	Multi-Channel Seismic
MFA	Mid-frequency Active (sonar)
min	minute
MMPA	(U.S.) Marine Mammal Protection Act
ms	millisecond
NMFS	(U.S.) National Marine Fisheries Service
nmi	nautical mile
NMML	National Marine Mammal Laboratory
NOAA	National Oceanic and Atmospheric Administration
NPFMC	North Pacific Fisheries Management Council
NRC	(U.S.) National Research Council
NSF	National Science Foundation
OBS	Ocean Bottom Seismometer
OEIS	Overseas Environmental Impact Statement
p or pk	peak
PBR	Potential Biological Removal
PEIS	Programmatic Environmental Impact Statement
PI	Principal Investigator
PTS	Permanent Threshold Shift
PSO	Protected Species Observer
QAA	Qualitative Analysis Area
rms	root-mean-square
R/V	research vessel
s	second
SBP	Sub-bottom Profiler
SEL	Sound Exposure Level (a measure of acoustic energy)
SIDEx	Sea Ice Dynamics Experiment
SPL	Sound Pressure Level
SODA	Stratified Ocean Dynamics of the Arctic
SOSUS	(U.S. Navy) Sound Surveillance System
t	tonnes
TTS	Temporary Threshold Shift
U.K.	United Kingdom
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
U.S.	United States of America
USCGC	U.S. Coast Guard Cutter
USGS	U.S. Geological Survey
USFWS	U.S. Fish and Wildlife Service
µPa	microPascal
VLF	very low frequency
vs.	versus
WCMC	World Conservation Monitoring Centre
y	year
YK	Yukon-Kuskokwim

I Purpose and Need

This Draft Environmental Assessment/Analysis (EA) addresses NSF's requirements under the National Environmental Policy Act (NEPA) and 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, seabirds, fish, and invertebrates. The Draft EA will also be used in support of other regulatory processes, including an application for an Incidental Harassment Authorization (IHA) and Section 7 consultations under the Endangered Species Act (ESA) with the National Marine Fisheries Service (NMFS) and the U.S. Fish and Wildlife Service (USFWS). 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

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

1.2 Purpose of and Need for the Proposed Action

As noted in the PEIS, § 1.3, NSF has a continuing need to fund seismic surveys that enable scientists to collect data essential to understanding the complex Earth processes beneath the ocean floor. The purpose of the proposed study is to use two-dimensional (2-D) seismic reflection data to document the history, structure, and stratigraphy of the Chukchi Borderland and adjacent Canada Basin, and to use ocean bottom seismometer (OBS) seismic refraction data in the Canada Basin to characterize the deep crustal structure associated with an extinct mid-ocean ridge in the central basin. The proposed activities would collect data in support of a research proposal that has been reviewed through the NSF merit review process and have been identified as NSF program priorities to meet the agency's critical need to foster an understanding of Earth processes. It would also image sites for potential future scientific ocean drilling under the International Ocean Discovery Program (IODP).

[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-funded Marine Seismic Research

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

1.4 Regulatory Setting

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

- Executive Order 12114;
- National Environmental Protection Act (NEPA);
- Marine Mammal Protection Act (MMPA);
- Endangered Species Act (ESA); and
- Magnuson-Stevens Fishery Conservation and Management Act - Essential Fish Habitat (EFH).

II ALTERNATIVES INCLUDING PROPOSED ACTION

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

2.1 Proposed Action

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

2.1.1 Project Objectives and Context

Researchers from the University of Alaska have proposed to conduct seismic surveys using R/V *Sikuliaq* in the Arctic Ocean (Fig. 1). Although not funded through NSF, collaborator Dr. J.R. Hopper (Geological Survey of Denmark and Greenland) would work with the Principal Investigator (PI), Dr. B. Coakley, to achieve the research goals, providing assistance such as through logistical support, and data acquisition, processing, and exchange; some NSF funding would provide support for international engineer participation and equipment use. The following information provides an overview of the project objectives associated with the marine surveys.

The Chukchi Borderland is a block of extended continental crust embedded in the deep water Amerasia Basin. To understand the opening of this basin, it is necessary to restore the Borderland to its pre-opening position. The choice of this position distinguishes tectonic models of the basin. Better understanding the history of the Borderland and the surrounding structures would provide critical constraint on the history of the Amerasia Basin and the continents adjacent to it. In this area, three of the major structures of the Amerasia Basin intersect; the Borderland, Alpha Ridge, and Canada Basin. Dedicated seismic surveys in this region would improve our understanding of these structures and their termination or continuation below the sediment cover. The proposed surveys would elucidate the relations between the overtly continental, high-standing block and the surrounding crust, which may be, in part, of continental composition as well.

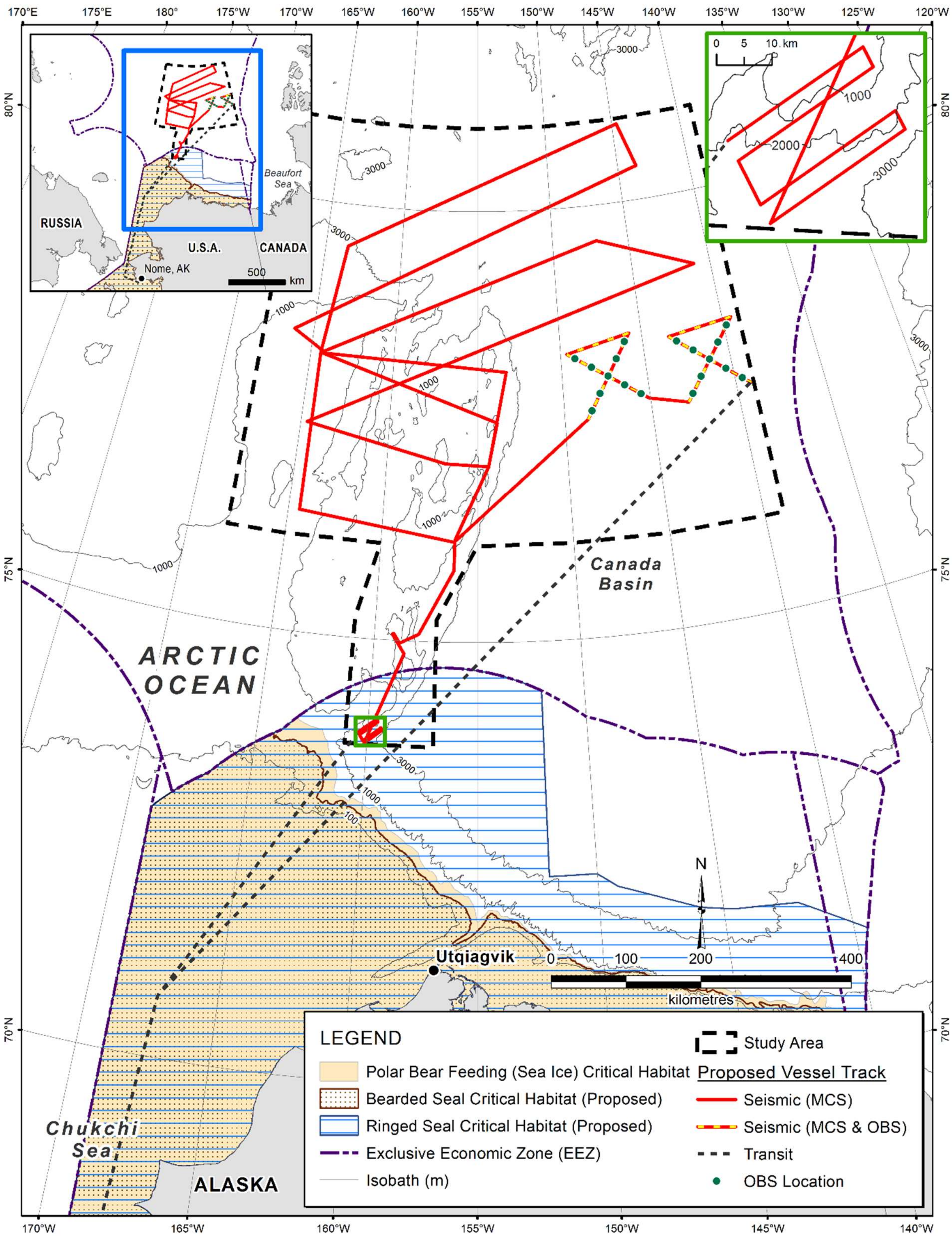

FIGURE 1. Location of the proposed seismic surveys and OBS deployment locations in the Arctic Ocean.

The main goal of the seismic program proposed by the University of Alaska is to map the northern edge in the Chukchi Borderland and the adjacent Canada Basin. To achieve the project goal, the PI Dr. B. Coakley proposes to utilize 2-D seismic reflection and OBS seismic refraction capabilities to address the following objectives:

1. Reveal the crustal structure of the Northern Chukchi Borderland, an extinct mid-ocean ridge and the adjacent extended continental crust.
2. Establish relations between continental Chukchi Borderland and transitional and oceanic crust in the Canada Basin.
3. Identify continuation of the mid-ocean ridge.
4. Link up lines collected by Canada for their Extended Continental Shelf program.
5. Sample distinct pieces of seafloor that have not previously been observed.
6. Image sites for proposed scientific ocean drilling.
7. Gather information that could be useful for a U.S. claim of an extended continental shelf for seabed resources under Article 76 of the Law of the Sea.

2.1.2 Proposed Activities

2.1.2.1 Location of the Survey Activities

The proposed surveys would occur within ~73.5–81.0°N, ~139.5–168°W, and ~300 km from the Alaska coastline. Representative survey tracklines are shown in Figure 1. As described further in this document, however, some deviation in actual tracklines, including the order of survey operations, could be necessary for reasons such as science drivers, poor data quality, inclement weather, subsistence or mechanical issues with the research vessel and/or equipment. Thus, for the surveys, the tracklines could occur anywhere within the coordinates noted above and within the study area shown in Figure 1. The surveys are proposed to occur within the Exclusive Economic Zones (EEZ) of the U.S. and in International Waters ranging in depth from 200 to 4000 m. The Proposed Action would occur ≥300 km north of Utqiaġvik.

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 NSF-funded surveys and would use conventional seismic methodology. The survey would involve one source vessel, R/V *Sikuliaq*, which would tow an array with up to 6 G-airguns (520 in^3 each) and a total possible discharge volume of ~3120 in^3 at a depth of 9 m. During low-energy multi-channel seismic (MCS) reflection surveys, a 2-airgun array would be used with a total discharge volume of 1040 in^3, and a high-energy 6-airgun, 3120 in^3, array would be employed during OBS refraction surveys. During MCS surveys (~88% of total line km), a 1–3 km long hydrophone streamer (depending on ice conditions) would be employed as the receiving system, and refraction surveys (~12% of total line km) would employ 9 OBS as the receiving system. As the airgun arrays are towed along the survey lines, the OBSs would receive and store the returning acoustic signals internally for later analysis, and the hydrophone streamer would transfer the data to the on-board processing system. The airguns would fire at a shot interval of 35 m (~15 s) during MCS surveys and at a 139-m (~60 s) interval during OBS refraction surveys.

In addition to numerous MCS transect lines, some lines would be acquired twice – once for MCS reflection and again for OBS refraction surveys. These MCS/OBS surveys would take place near the end of operations in the northeastern part of the survey area (Fig. 1); however, the location of these surveys could shift slightly to ensure one survey occurs over the extinct ridge axis and the other on hyper-extended continental crust. A total of nine OBSs would be deployed twice for a total of 18 deployment sites. Nine OBSs would be deployed while MCS data would be acquired between OBS drops, then OBS refraction data would be acquired along these same lines, followed by retrieval of the OBSs, before R/V *Sikuliaq* would travel to the next site to deploy all nine OBSs again. Approximately 5850 line km would be surveyed, including 5170 km of MCS surveys, and 680 km of OBS surveys. There could be additional seismic operations associated with turns, airgun testing, and repeat coverage of any areas where initial data quality is sub-standard. In the take calculations (see § 4.1.1.5), 25% has been added in the form of operational days which is equivalent to adding 25% to the proposed line km to be surveyed. Most of the survey (80%) would occur in deep water (>1000 m), and 20% would occur in intermediate water (100–1000 m deep); there would be no effort in shallow water <100 m deep.

In addition to the operations of the airgun array, a multibeam echosounder (MBES), sub-bottom profiler (SBP), and Acoustic Doppler Current Profiler (ADCP) would be operated from R/V *Sikuliaq* during the seismic surveys. All planned geophysical data acquisition activities would be conducted by the University of Alaska with on-board assistance by the scientists and engineers 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 study would be expected to last for ~45 days, including ~30 days of seismic operations, ~8 days of transit to and from the survey area, and 7 days for equipment deployment/recovery. R/V *Sikuliaq* would likely leave out of and return to port in Nome, AK, during summer (August/September) 2021. As R/V *Sikuliaq* is a national asset, NSF and the University of Alaska strive to schedule its operations in the most efficient manner possible; schedule efficiencies are achieved when regionally occurring research projects are scheduled consecutively and non-operational transits are minimized. Because of the nature of the NSF merit review process and the long timeline associated with the ESA Section 7 consultation and IHA processes, not all research projects or vessel logistics are identified at the time the consultation documents are submitted to federal regulators; typically, however, these types of details, such as port arrival/departure locations, are not a substantive component of the consultations. The ensuing analysis (including take estimates) focuses on the time of the survey (August/September); the best available species densities for that time of the year have been used.

2.1.2.4 Vessel Specifications

R/V *Sikuliaq* has a length of 80 m, a beam of ~16 m, and a draft of ~6 m. The ship has diesel-electric engine with 5750 bhp, and can break through ice up to 1 m thick. The cruising speed is 10 kt, and the range is 18,000 n.mi. with an endurance of 45 days. The vessel speed during seismic operations would be ~4.5 kt (~8.3 km/h).

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

Owner:	NSF
Operator:	University of Alaska
Flag:	U.S.
Date Built:	2014
Gross Tonnage:	3429
Accommodation Capacity:	46 including ~24 scientists

2.1.2.5 Airgun Description

During the surveys, R/V *Sikuliaq* would tow up to 6 G-airguns. During MCS surveys, 2 G-airguns with a total discharge volume of 1040 in^3 would be used; during OBS surveys, a 6-airgun 3120 in^3 array would be employed. Various airgun arrays were described in § 2.2.3.1 of the PEIS. The array would be towed at a depth of 9 m, and the shot interval would be 35 m (~15 s) during MCS surveys, 139 m (60 s) during refraction surveys.

2.1.2.6 OBS Description

Nine OBSs would be deployed at two sites within the Canada Basin in the northeastern portion of the survey area (Fig. 1). The OBSs would be deployed 25 km apart along two lines; after seismic acquisition at the first site, they would be retrieved and redeployed at the second site. The OBSs used would be Sercel MicrOBS. OBSs have a height and diameter of ~1 m and an anchor weighing ~80 kg. All OBSs would be recovered upon conclusion of the survey.

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 *Sikuliaq* during the proposed surveys. The ocean floor would be mapped with the Kongsberg EM 302 MBES at 30 kHz and a Kongsberg TOPAS PS-18 SBP, operating at 0.5–6.0 kHz. The ADCP is the Teledyne RDI OS, that operates at frequencies of 75 kHz and 150 kHz. Similar sound sources are described in § 2.2.3.1 of the PEIS. To retrieve OBSs, an acoustic release transponder (pinger) is used to interrogate the instrument at a frequency of 10–11 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. The sources proposed already are relatively small energy sources (most of the acquisition would use a 2-airgun, 1040 in^3 array), and the scientific objectives for the proposed surveys could not be met using smaller sources. The 2-airgun array would be needed to penetrate substantial thicknesses of sediment expected to be encountered in the Canada Basin. Recognizing the structures associated with the extinct mid-ocean ridge and adjacent possible hyper-extended continental crust in the Canada Basin is also an important objective. On the Chukchi Borderland, there appear to be substantial basement structures beneath the sediment cover. Imaging these structures is critical to understanding the pre-extension history of the Borderland. The 2-airgun array was considered the minimum that would provide sufficient energy to image the stratigraphy and underlying structure.

***Survey Location and Timing*.—**The PI worked with NSF to consider potential times to carry out the proposed surveys, key factors taken into consideration included environmental conditions (i.e., ice cover, seasonal presence of marine mammals and seabirds), subsistence activities weather conditions, equipment, and optimal timing for other proposed research cruises using R/V *Sikuliaq*, as well as coordination with the Geological Survey of Denmark and Greenland. The schedule is mainly constrained by the ice-minimum (~15 September) and consideration of subsistence activities in the region (i.e., seismic surveys would occur ≥300 km north of Utqiaġvik). Working north of the Chukchi Borderland around the time of the ice-minimum enables the longer lines to be acquired. R/V *Sikuliaq* is expected to encounter only limited ice in the marginal ice zone during this cruise. Arriving earlier risks heavier residual ice from the previous season, whereas arriving later risks encountering fresh annual ice that could impair operations. The plan is to have all the gear on board and be southbound to Nome prior to the beginning of fall whaling in Utqiaġvik. Therefore, summer is the most practical season for the proposed surveys.

***Mitigation Zones*.—**During the planning phase, mitigation zones for the proposed marine seismic surveys were not derived from the farfield signature but based on modeling by Lamont-Doherty Earth Observatory (L-DEO) of Columbia University for the exclusion zones (EZ) for Level A takes and for the Level B (160 dB re 1µPa_{rms}) threshold. The background information and methodology for this are provided in Appendix A. The proposed surveys would acquire MCS data with a 2 G-airguns and OBS refraction data with a 6 G-airgun array, at a maximum tow depth of 9 m. L-DEO model results are used to determine the 160-dB_{rms} radius for the airgun arrays at a 9-m tow depth in deep water (>1000 m) down to a maximum depth of 2000 m, as animals are generally not anticipated to dive below 2000 m (Costa and Williams 1999). The radii for intermediate water depths (100–1000 m) are derived from the deep-water ones by applying a correction factor of 1.5. Table 1 shows the distances at which the 160-dB re 1µPa_{rms} sound levels are expected to be received for the 2- and 6-airgun arrays. The 160-dB level is the behavioral disturbance criterion (Level B) that is used by NMFS to estimate anticipated takes for marine mammals.

The thresholds for permanent threshold shift (PTS) onset or Level A Harassment (injury) for marine mammals for impulsive sounds use dual metrics of cumulative sound exposure level (SEL_{cum} over 24 hours) and peak sound pressure levels (SPL_{flat}). Different thresholds are provided for the various hearing groups, including low-frequency (LF) cetaceans (e.g., baleen whales), mid-frequency (MF) cetaceans (e.g., most delphinids), high-frequency (HF) cetaceans (e.g., harbor porpoise and *Kogia* spp.), phocids underwater (PW), and otariids and other non-phocid carnivores underwater (OW) (NMFS 2016a, 2018). 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 for the 2 G-airguns (Table 2) and 6 G-airguns (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 recent NSF-funded, high-energy seismic surveys, 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. Enforcement of mitigation zones via shut downs would be implemented as described below

TABLE 1. Level B. Predicted distances to which sound levels ≥160-dB could be received during the proposed surveys in the Arctic Ocean. The 160-dB criterion applies to all hearing groups of marine mammals.

Source and Volume[1]	**Tow Depth (m)**	**Water Depth (m)**	**Predicted distances (in m) to the 160-dB Received Sound Level**
Two 520 in^3 G-airguns, 1040 in^3	9	>1000 m	1604[2]
		100–1000 m	2406[3]
Six 520 in^3 G-airguns, 3120 in^3	9	>1000 m	4640[2]
		100–1000 m	6960[3]

[1] Modeled at 2540 psi.
[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 threshold distances for different marine mammal hearing groups for the 2 G-airguns and shot interval of 15 s. 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 and other Non-phocid Carnivores
PTS SEL_{cum}	**17.2**	0	0	0.2	0
PTS Peak	10.3	**2.9**	**72.8**	**11.6**	**2.3**

TABLE 3. Level A threshold distances for different marine mammal hearing groups for the 6 G-airguns and a shot interval of 60 s. 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 and other Non-phocid Carnivores
PTS SEL_{cum}	**50.6**	0	0	0.4	0
PTS Peak	29.8	**7.2**	**211.5**	**33.6**	**5.1**

2.1.3.2 Operational Phase

Marine mammals are known to occur in the proposed survey area. However, the number of individual animals expected to be approached closely during the proposed activities are expected to be relatively small in relation to regional population sizes. 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, 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).

Five independently contracted PSOs would be on board the survey vessel with rotating shifts to allow two observers to monitor for marine species during daylight hours, and one observer to conduct PAM during day- and night-time seismic operations. The proposed operational mitigation measures are standard for all seismic cruises, per the PEIS, and are described in the IHA application, and not discussed further here. Special mitigation measures were considered for this cruise; it is unlikely that concentrations of large whales would be encountered within the 160-dB isopleth, but if they were, they would be avoided. With the proposed monitoring and mitigation provisions, potential effects on most, if not all, individuals would be expected to be limited to minor behavioral disturbance. Those potential effects would be expected to have negligible impacts both on individual marine mammals and on the associated species and stocks. Given the relatively small energy source and survey location, an additional support vessel with additional PSOs would not be warranted or practical. Ultimately, survey operations would be conducted in accordance with all applicable U.S. federal regulations, including IHA and ITS requirements.

2.2 Alternative 1: No Action Alternative

An alternative to conducting the Proposed Action is the "No Action" alternative, i.e., do not issue an IHA and do not conduct the research operations (Table 4). Under the "No Action" alternative, NSF would not support the University of Alaska 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, the University of Alaska 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

This location where three major structures of the Amerasia Basin intersect is ideally suited for the proposed study in support of the project objectives to document the history, structure, and stratigraphy of the Chukchi Borderland and adjacent Canada Basin. The data that would be collected could expand our understanding of the formation of ocean basin and the processes of ultra-slow seafloor spreading, and improve our knowledge of the adjacent continents and Cretaceous tectonics of the region.

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

Proposed Action	Description
Proposed Action: Conduct marine geophysical surveys and associated activities in the Arctic Ocean	Under this action, research activities are proposed to study earth processes and would involve 2-D seismic surveys. Active seismic portions would be expected to take ~30 days, and additional operational days would be expected for transit; equipment deployment, maintenance, and retrieval; weather; marine mammal activity; and other contingencies. The affected environment, environmental consequences, and cumulative impacts of the proposed activities are described in § III and IV. The standard monitoring and mitigation measures identified in the PEIS would apply, along with any additional requirements identified by U.S. regulating agencies. All necessary permits and authorizations, including an IHA, would be requested from regulatory bodies.
Alternatives	Description
Alternative 1: No Action	Under this Alternative, no proposed activities would be conducted and seismic data would not be collected. While this alternative would avoid impacts to marine resources, it would not meet the purpose and need for the Proposed Action. Geological data of scientific value and relevance regarding the constraints on basin history and crustal structure of the Amerasia Basin, information that could be useful for a U.S. claim of an extended continental shelf for seabed resources under Article 76 of the Law of the Sea, and data needed for a future IODP project, would not be collected. The collection of new data, interpretation of these data, and introduction of new results into the greater scientific community and applicability of these data to other similar settings would not be achieved. No permits and authorizations, including an IHA, would be needed from regulatory bodies, as the Proposed Action would not be conducted.
Alternatives Eliminated from Further Analysis	Description
Alternative E1: Alternative Location	Three major structures of the Amerasia Basin intersect in the study area; the Borderland, Alpha Ridge, and Canada Basin. Better understanding of the Borderland and the surrounding structures would provide critical constraint on the history of the Amerasia Basin and the continents adjacent to it, and identify continuation of the mid-ocean ridge. The data that would be collected could expand our understanding of the formation of ocean basin and the processes of ultra-slow seafloor spreading, and improve our knowledge of the adjacent continents and Cretaceous tectonics of the region. The proposed science underwent the NSF merit review process, and the science, including the site location, was determined to be meritorious.
Alternative E2: Use of Alternative Technologies	Under this alternative, the University of Alaska would use alternative survey techniques, such as marine vibroseis, that could potentially reduce impacts on the marine environment. Alternative technologies were evaluated in the PEIS, § 2.6. At this time, however, these technologies are still not feasible, commercially viable, or appropriate to meet the Purpose and Need.

2.3.2 Alternative E2: Use of Alternative Technologies

As described in § 2.6 of the PEIS, alternative technologies to the use of airguns were investigated to conduct 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 2014).

III AFFECTED ENVIRONMENT

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

- *Air Quality/Greenhouse Gases*—Project vessel emissions would result from the proposed activity; however, these short-term emissions would not result in any exceedance of Federal Clean Air standards. Emissions would be expected to have a negligible impact on the air quality within the proposed survey area;
- *Land Use*—All activities are proposed to occur in the marine environment. Thus, no changes to current land uses or activities in the proposed survey area would result from the Project;
- *Safety and Hazardous Materials and Management*—No hazardous materials would be generated or used during the proposed activities. All Project-related wastes would be disposed of in accordance with international, U.S. state, and federal requirements;
- *Geological Resources (Topography, Geology and Soil)*—The proposed Project would result in very minor disturbance to seafloor sediments from OBS deployments during the surveys; small anchors would not be recovered. The proposed activities would not significantly impact geologic resources;
- *Water Resources*—No discharges to the marine environment that would adversely affect marine water quality are expected in the Project area. Therefore, there would be no impacts to water resources resulting from the proposed Project activity;
- *Terrestrial Biological Resources*—All proposed Project activities would occur in the marine environment and would not impact terrestrial biological resources;
- *Visual Resources*—No visual resources would be expected to be negatively impacted as the proposed activities would be short-term and located far from shore;
- *Socioeconomic and Environmental Justice*—Implementation of the proposed project would not affect, beneficially or adversely, socioeconomic resources, environmental justice, or the protection of children. No changes in the population or additional need for housing or schools would occur. Human activities would be limited within the Project area. Thus, no socioeconomic impacts would be anticipated as result of the proposed activities.
- *Cultural Resources*—There are no known cultural resources within the proposed survey area. Thus, no impacts to cultural resources (e.g., shipwrecks, archeological sites) would be expected. Although subsistence hunting and fishing occur within the nearshore waters of Alaska, the proposed activities would not be expected to impact those activities, as the proposed activities would occur >300 km from shore. Nonetheless, subsistence activities are discussed in § IV.

3.1 Oceanography

The Arctic Ocean is the smallest of the world's oceans, covering 14,090,000 km^2 (Encyclopædia Britannica 2021). The greatest depth recorded in the Arctic Ocean is 5502 m, although the average depth is 987 m. The Arctic Ocean consists of two main deep basins that can be further subdivided into four smaller basins by three transoceanic ridges – the Lomonosov, Nansen-Gakkel, and Alpha ridges. The Lomonosov Ridge is the central ridge that extends from the shelf off Ellesmere Island to the New Siberian Islands, that has an average relief of ~3000 m and divides the Arctic Ocean into two basins: the Eurasia Basin and the Amerasia Basin. The Nansen-Gakkel Ridge transects the Eurasia Basin into Amundsen Basin and Nansen Basin, and the Amerasia Basin is further divided by the Mendeleev Ridge–Alpha Ridge complex into the Makarov Basin and the Canada Basin.

There are three main water masses in the Arctic Ocean: (1) relatively fresh, low-salinity Arctic surface water, (2) an intermediate layer that is composed of warmer, saltier Atlantic water, which enters north of Spitzbergen, and (3) Arctic bottom water that is cold, deep water which flows in across the submarine ridge between Spitzbergen and Greenland (Sverdrup et al. 1942; McLaughlin et al. 1996). Surface water enters the Arctic Ocean from the Pacific Ocean through the Bering Strait and from the Atlantic Ocean through eastern Fram Strait (UN 2016). During the summer, these water sources are modified by river runoff and meltwater, and in the winter, salt rejection during freezing; this results in a brackish surface layer with lower salinity (UN 2016). A smaller water quantity flows southward through the Barents and Kara seas and the Canadian Archipelago (Encyclopædia Britannica 2021). Approximately 2% of the water entering the Arctic Ocean is fresh water, and precipitation in the region is ~10 times greater than loss by evaporation (Encyclopædia Britannica 2021). Two water masses are evident within the bottom layer: (1) Eurasian Basin deep water, and (2) Canadian Basin deep water, separated by the Lomonsonov Ridge (Woodgate et al. 2001). Arctic surface waters are driven by wind and density differences and by a clockwise surface circulation pattern. The deep boundary current in the Arctic Ocean appears to be characterized by weak mean flows and strong, isolated eddies (Aagaard 1989; Woodgate et al. 2001). A front runs along the Mendeleyev-Alpha Ridge (Belkin et al. 2009), along the western edge of the proposed survey area.

The Arctic ice cover opens significantly during summer in coastal seas north of Asia, Alaska, and Canada (UN 2016). Sea ice rarely forms in the open ocean below 60ºN; between 60ºN and 75ºN it is present seasonally (Belkin et al. 2009). Above 75ºN, ice cover is typically present on a largely permanent basis. The Arctic has notable year-to-year variations in ice cover although an increasing trend in the retreat of the pack ice has been documented over the last few decades (Stroeve et al. 2008; Belkin et al. 2009; Thoman et al. 2020). When ice is present it suppresses wind stress and wind mixing and also reflects solar radiation, thereby lowering surface temperature and impeding evaporation. Wind and surface stresses keep the ice pack in constant motion, resulting in the formation of leads, polynyas, pressure ridges, shear zones, and other features.

Although the Arctic Ocean is generally considered a low productivity ecosystem (UN 2016). Pabi et al. (2008 *in* Belkin et al. 2009) reported an annual average pan-Arctic primary production of 419 $\pm$ 33 Tg C. Sakshaug (2003 *in* Belkin et al. 2009) reported an annual primary production of 50 Tg C for the deeper parts of the Arctic Ocean. Nonetheless, the Chukchi Sea (Day et al. 2013a) and the Beaufort Sea (Forster et al. 2020) have both been described as relatively biologically productive due to ice melt in the spring/summer months that produces phytoplankton blooms, and ice-covered zones in winter months lead to high within-ice production (Day et al. 2013a). The survey area extends from relatively shallow near the Central Channel and Hanna Shoal (>200 m deep) to deeper areas beyond the continental shelf break.

These areas of topographic heterogeneity are associated with upwelling zones (Harwood et al. 2015) which may also infer greater species richness. The warming of the oceans due to climate change is expected to reduce sea ice cover in the Chukchi Sea which will permit longer production seasons and phytoplankton blooms (Hunt et al. 2013).

3.2 Protected Areas

3.2.1 Critical Habitat in Alaska

Habitats near or within the proposed survey area have been specifically identified as important to U.S. ESA-listed marine mammal species. Critical habitat in Alaska includes areas designated in the Bering Sea and/or Gulf of Alaska for the North Pacific right whale, Cook Inlet beluga, sea otter, Steller sea lion, and Steller's eider. The USFWS has also established critical habitat for spectacled eiders in the Bering Sea and Chukchi Sea (Ledyard Bay). Critical habitat has also been proposed for the humpback whale in the Bering Sea, Gulf of Alaska, and southeast Alaska (NMFS 2019a). None of the aforementioned critical habitat occurs near the proposed survey area. Only critical habitat for the polar bear, and proposed critical habitat for ringed and bearded seals are discussed here, as these habitats occur in the Chukchi and Beaufort seas, near the proposed survey area. There is no critical habitat for fish or marine invertebrate species in Alaska.

***Polar Bear Critical Habitat*.—**On 7 December 2010, critical habitat for polar bear was listed (50 CFR Part 17). The critical habitat is designated in three units: sea-ice critical habitat, terrestrial denning critical habitat, and barrier island critical habitat (USFWS 2010). Only the sea-ice critical habitat is relevant here; it occurs within the U.S. EEZ in the Beaufort and Chukchi seas (Fig. 1). The sea-ice critical habitat includes all contiguous waters from mainland Alaska out to the 300-m isobath, and extends from the U.S.-Canada border to the U.S.-Russian boundary, and southwards to 61.5°N in the east and 62.6°N in the west. Although the proposed vessel transit transects the critical habitat in the Bering Strait and Chukchi seas, it is located ~44 km south of the proposed survey area (Fig. 1). The cruise would only overlap sea-ice critical habitat if sea ice was actually present in the area where R/V *Sikuliaq* would be transiting. As R/V *Sikuliaq* would be avoiding pack ice, neither polar bears nor their critical habitat are likely to occur within the seismic survey area.

***Ringed Seal Proposed Critical Habitat*.—**Critical habitat for the Arctic subspecies of ringed seal was first proposed in December 2014 (NMFS 2014). Revisions to the proposed critical habitat were made in January 2021 (NMFS 2021a). Critical habitat was proposed to include nearly all waters of the U.S. EEZ in the Chukchi and Beaufort seas, as well as a portion of the Bering Sea (Fig. 1). Essential physical features of the habitat include snow-covered ice suitable for subnivean birth lairs and sea ice habitat of 15% concentration or greater suitable for basking and molting (NMFS 2021a). The southern portion of the proposed seismic survey area, as well as the proposed transit through the Bering Strait and Chukchi seas, occur within proposed critical habitat (Fig. 1).

***Pacific Bearded Seal Proposed Critical Habitat*.—**Critical habitat for the Beringia DPS of Pacific bearded seal was first proposed in January 2021 (NMFS 2021b). Critical habitat has been proposed to include waters of the U.S. EEZ within the 200-m depth contour, including portions of the Chukchi and Beaufort seas, as well as parts of the Bering Sea (Fig. 1). Essential physical features of the habitat include areas with 25% ice cover where the sea ice suitable for nursing and whelping, and habitat with 15% ice cover with sea ice suitable for molting (NMFS 2021b). Although the proposed seismic survey area does not occur within the proposed critical habitat (the survey area is located 63 km to the north), the transit through the Bering Strait and Chukchi Sea would transect the proposed critical habitat (Fig. 1).

3.2.2 Other Conservation Areas in the Region

The survey area is located within two Convention on Biological Diversity (CBD)-designated Ecologically or Biologically Significant Marine Areas (EBSA). Almost the entire survey, except for the portion occurring within the U.S. EEZ and a few areas at the northern end of the survey area, would occur within the Marginal Ice Zone and the Seasonal Ice-Cover Over the Deep Arctic Ocean EBSA. This EBSA covers a large area of the central Arctic Ocean basins >500 m deep, that have annual ice and therefore ice edge and seasonal ice zones with open water during the summer (CBD 2021). Changes in sea ice affect primary productivity which in turn affects the rest of the ecosystem. The marginal ice zone provides important foraging areas for ice-associated species, as well as important habitats for breeding, molting, and resting (CBD 2021). The northern portion of the survey area also falls within the Multi-Year Ice EBSA. This EBSA is likely to retain ice longer than other areas of the Arctic and could therefore serve as a refuge for ice-dependent species such as the polar bear, as sea ice loss continues (CBD 2021).

The Wrangel-Herald Shallow and Ratmanov Gyre EBSA is located ~527 km to the southwest of the proposed survey area. The Wrangel Island Reserve, Russia, is located ~640 km from the nearest proposed seismic line. Conservation areas with marine habitat in Alaska include the Arctic National Wildlife Refuge in the Beaufort Sea, and the Alaska Maritime National Wildlife Refuge, Cape Krusenstern National Monument, and Bering Land Bridge National Park and Reserve, in the Chukchi Sea; all are located 600 km or more from the nearest proposed seismic line. The closest marine protected areas (MPAs) in Canada (Tarium Niryutait and Anguniaqvia niqiqyuam MPAs) are located >900 km to the southeast. The vessel would also transit through the IUCN designated Beringia Heritage International Park.

3.3 Marine Mammals

A total of nine cetacean species, five species of pinnipeds, and one marine fissiped could occur in or near the proposed study area (Table 5). Four of these species/populations, including the bowhead whale, fin whale, Western North Pacific DPS of gray whale, and Western North Pacific DPS of humpback whale are listed as ***endangered*** under the ESA. The ***threatened*** polar bear, Mexico DPS of humpback whale, Beringia DPS of bearded seal, and Arctic subspecies of ringed seal could also occur in or near the survey area.

The marine mammals that could be encountered in the proposed survey area belong to three taxonomic groups: odontocetes (toothed cetaceans, such as beluga whale and narwhal), mysticetes (baleen whales), and carnivora (pinnipeds and polar bears). Cetaceans and pinnipeds (except walrus) are the subject of the IHA Application to NMFS; in the U.S., the walrus and polar bear are managed by USFWS. The marine mammal species most likely to be encountered during the seismic survey include the beluga whale and the ringed seal. The bowhead whale and bearded seal likely occur in low numbers and are most common within 100 km of shore, where no seismic work is proposed. Seven additional cetacean species—narwhal, killer whale, harbor porpoise, gray whale, minke whale, fin whale, and humpback whale—could occur in the project area but are unlikely to be encountered during the survey because they are primarily coastal species or rare because they are outside of their normal range in the survey area in the Arctic Ocean. Nonetheless, these seven species have been included here for the sake of completeness. The gray whale is a coastal species that occurs regularly in continental shelf waters along the Chukchi Sea coast in summer and to a lesser extent along the Beaufort Sea coast. Monitoring activities in the Chukchi and Beaufort seas during industry seismic surveys suggest that the harbor porpoise, also a coastal species, and the minke whale, both of which have been considered uncommon or rare in the Chukchi and Beaufort seas, may be increasing in numbers in these areas (e.g., Funk et al. 2010). Similarly, Brower et al. (2018) also noted that sightings of

TABLE 5. The habitat, abundance, and conservation status of marine mammals that could occur in or near the proposed study area in the Arctic Ocean.

Species	Occurrence in Area*	Habitat	Regional Abundance	ESA[1]	IUCN[2]	CITES[3]
Mysticetes						
Bowhead whale *Balaena mysticetus*	Uncommon	Pack ice, coastal	16,820[4] 27,133[5]	EN	LC	I
Gray whale *Eschrichtius robustus*	Rare	Coastal, lagoons	26,960[6]	DL/EN[25]	LC	I
Humpback whale *Megaptera novaeangliae*	Rare	Shelf, coastal	10,103[7] 1,107[8]	T/EN[26]	LC	I
Common minke whale *Balaenoptera acutorostrata scammoni*	Rare	Shelf, coastal	20,000[9]	NL	LC	I
Fin whale *Balaenoptera physalus physalus*	Rare	Slope, mostly pelagic	13,620-18,680[10]	EN	VU	I
Odontocetes						
Beluga whale *Delphinapterus leucas*	Common	Offshore, coastal, ice edges	20,752[11] 39,258[12]	NL	LC	II
Narwhal *Monodon monoceros*	Rare	Offshore, ice edges	N.A.[13]	NL	LC	II
Killer whale *Orcinus orca*	Rare	Widely distributed	2,347[14] 587[15]	NL	DD	II
Harbor porpoise *Phocoena phocoena vomerina*	Rare	Coastal, inland waters, shallow offshore waters	48,215[16]	NL	LC	II
Pinnipeds						
Pacific walrus *Odobenus rosmarus divergens*	Uncommon	Coastal, pack ice, ice floes	129,000[17]	NL	DD	III
Bearded seal *Erignathus barbatus nauticus*	Uncommon	Pack ice, open water	125,000[18] 301,836[19]	T	LC	–
Spotted seal *Phoca largha*	Uncommon	Pack ice, open water, coastal haulouts	461,625[19]	NL	LC	–
Arctic ringed seal *Phoca (pusa) hispida*	Common	Landfast ice, pack ice, open water	171,418[19] 119,000[18] 300,000[20] 208,000[21]	T	LC	–
Ribbon seal *Histriophoca fasciata*	Uncommon	Pack ice, open water	184,697[19]	NL	LC	–
Ursids						
Polar bear *Ursus maritimus*	Uncommon	Pack ice	2937[22]; 980[23]; 907[24]	T	VU	II

N.A. = not available. * Based on literature and professional judgement. [1] U.S. Endangered Species Act (ESA; NOAA 2021a): EN = Endangered, T = Threatened, NL = Not listed, DL = Delisted. [2] Classification from the International Union for the Conservation of Nature (IUCN) Red List of Threatened Species (IUCN 2020); EN = Endangered; VU = Vulnerable; LC = Least Concern; DD = Data Deficient. [3] Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES; UNEP-WCMC 2020): Appendix I = Threatened with extinction; Appendix II = not necessarily now threatened with extinction but may become so unless trade is closely controlled; Appendix III: protected in at least one country, which has asked other CITES Parties for assistance in controlling the trade. [4] Western Arctic stock based on 2011 aerial surveys (Givens et al. 2016 *in* Muto et al. 2020). [5] Western Arctic stock based on 2011 photo-identification data (Givens et al. 2018 in Muto et al. 2020). [6] Eastern North Pacific population (Durban et al. 2017 *in* Carretta et al. 2020); Western North Pacific population is estimated at 290 animals (Carretta et al. 2020). [7] Central North Pacific stock (Muto et al. 2020). [8] Western North Pacific stock (Muto et al. 2020). [9] Northwest Pacific and Okhotsk Sea (IWC 2021). [10] North Pacific (Ohsumi and Wada 1974). [11] Eastern Chukchi Sea stock (Muto et al. 2020). [12] Beaufort Sea stock (Muto et al. 2020). [13] Baffin Bay and Canadian Arctic archipelago population (COSEWIC 2004). [14] Alaska Resident stock (Muto et al. 2020). [15] Gulf of Alaska, Aleutian Islands, and Bering Sea Transient stock (Muto et al. 2020). [16] Bering Sea stock (Muto et al. 2020). [17] 129,000 with a 95% CV of 55,000-507,000 (Speckman et al. 2011 *in* Muto et al. 2020). [18] 2013 estimate for U.S. portion of the Bering Sea (Boveng et al. 2017). [19] Alaska stock based on limited sub-sample from the Bering Sea (Conn et al. 2014 *in* Muto et al. 2020). [20] Chukchi and Beaufort seas (Kelly et al. 2010a). [21] Chukchi Sea (Bengtson et al. 2005). [22] Chukchi Sea population (IUCN/SCC PBSG 2020). [23] Northern Beaufort Sea population (IUCN/SCC PBSG 2020). [24] Southern Beaufort Sea population (IUCN/SCC PBSG 2020). [25] Although the Eastern North Pacific DPS was delisted under the ESA, the Western North Pacific DPS is listed as endangered. [26] The Western North Pacific DPS and Central America DPS are listed as endangered, and the Mexico DPS is listed as threatened; the Hawaii DPS is not at risk.

sub-Arctic species like minke, fin, and humpback whales are increasing in the eastern Chukchi Sea. Small numbers of killer whales have also been recorded during industry surveys in the Chukchi Sea, along with a few sightings of fin and humpback whales. The narwhal occurs in Canadian waters and occasionally in the Beaufort Sea, but is rare there and not expected to be encountered. It is very unlikely that a North Pacific right, blue, or sei whale would be encountered during the survey, although one sei whale was seen during U.S. Navy (2019a) research activities on 9 September 2019 just south of the survey area at 74.1°N, 166.5°W; these three species are not discussed further.

In addition to ringed and bearded seals, other pinniped species that could be encountered during the proposed survey include the spotted seal, ribbon seal, and Pacific walrus. Spotted seals are more abundant in the Chukchi Sea and occur in small numbers in the Beaufort Sea. The ribbon seal is uncommon in the Chukchi Sea, and there are few sightings in the Beaufort Sea. The Pacific walrus is common in the Chukchi Sea but uncommon in the Beaufort Sea, and not likely to occur in the far offshore waters of the proposed survey area in the Arctic Ocean. None of these species would likely be encountered during the proposed cruise other than perhaps during transit periods to or from the survey area. Polar bears occur on the pack ice in low densities. As the vessel will avoid the ice edge, it is unlikely that many polar bears would be encountered in the open-water study area.

General information on the taxonomy, ecology, distribution and movements, and acoustic capabilities of marine mammals are given in § 3.6.1, § 3.7.1, and § 3.8.1 of the PEIS. The rest of this section deals specifically with species distribution in the proposed survey area.

3.3.1 Mysticetes

3.3.1.1 Bowhead Whale (*Balaena mysticetus*)

The bowhead whale has a disjunct circumpolar distribution in arctic and subantarctic waters (Jefferson et al. 2015). Of four stocks recognized worldwide by the International Whaling Commission (IWC), the Bering-Chukchi-Beaufort (BCB) stock is the only one that could occur in the proposed survey area. The BCB stock winters in the central and western Bering Sea and summers in the Canadian Beaufort Sea and Amundsen Gulf (Moore and Reeves 1993; Quakenbush et al. 2018). However, some individuals spend the entire summer in the Chukchi Sea (Citta et al. 2012; Quakenbush et al. 2018). The eastern Bering Strait has been shown to be a Biologically Important Area (BIA) for the spring northbound migration in March–June (Ferguson et al. 2015a). Spring migration through the western Beaufort Sea occurs through offshore ice leads, generally from mid-April through mid-June (Braham et al. 1984; Moore and Reeves 1993).

The whales make the return migration west through the Alaskan Beaufort Sea in the fall to wintering areas in the Bering Sea. Some bowhead whales continue migrating west past Utqiaġvik (formerly Barrow) and through the Chukchi Sea to Russian waters before turning south toward the Bering Sea (Quakenbush 2007; Citta et al. 2018a). Some bowheads may reach ~75°N latitude during the westward fall migration (Quakenbush et al. 2010a; Citta et al. 2018a). Other researchers have also reported a westward movement of bowhead whales through the northern Chukchi Sea during fall migration (Moore et al. 1995, 2000a; Mate et al. 2000). Fall migration into Alaskan waters is primarily during September and October; westbound bowheads typically reach the Utqiaġvik area in mid-September (e.g., Brower 1996). However, small numbers of bowheads have been seen or heard offshore from the Prudhoe Bay region and seen near Utqiaġvik in August (e.g., Treacy 1993; LGL and Greeneridge 1996; Greene 1997; Greene et al. 1999, 2007; Blackwell et al. 2004, 2010; Huntington and Quakenbush 2009).

Bowheads tend to migrate west in deeper water (farther offshore) during years with higher-than-average ice coverage than in years with less ice (Moore 2000; Treacy et al. 2006). Treacy et al. (2006) found that the migration corridor ranges from ~30 km offshore during light ice years to ~80 km offshore during heavy ice years; sighting rate tends to be lower in heavy ice years (Treacy 1997). During fall migration, most bowheads migrate west in water ranging from 15 to 200 m deep over the continental shelf (Miller et al. 2002). Some individuals enter shallower water, particularly in light ice years, but very few whales are ever seen shoreward of the barrier islands in the Alaskan Beaufort Sea. Clarke et al. (2016) reported that there was no defined migratory corridor in the Chukchi Sea, and that bowheads occurred up to 300 km offshore to the west and southwest of Point Barrow. Migratory corridor BIAs have been described for the Bering Strait to the eastern Beaufort Sea during the spring migration, and along the northern Alaskan coast from Point Barrow eastward, during the fall migration (Clarke et al. 2015).

Citta et al. (2015, 2018b) reported concentration areas for bowhead whales off Point Barrow and in the eastern Beaufort Sea during summer. Similarly, based on Aerial Survey of Arctic Marine Mammals (ASAMM), Schick et al. (2017) also showed high densities of bowheads off Point Barrow and the Beaufort Sea during summer and into October. Additionally, Kuletz et al. (2015) reported hot spots in the same areas during summer and fall. Several areas in the nearshore waters of the Beaufort Sea have been identified as reproduction BIAs from spring through fall, based on calf sightings in the region (Clarke et al. 2015). The location and size of the BIA changes depending on the season. During spring, the BIA is located off Point Barrow; during July and August, it is located in the eastern Beaufort Sea; during September, a BIA has been identified from Point Barrow eastward; and during October, the BIA spans from west of Point Barrow all the way eastward along the Alaska coast (Clarke et al. 2015). The feeding BIAs change during the seasons as well, with a BIA located near Barrow Canyon in spring, within the 20-m isobath from Point Barrow to Smith Bay (just to the east) during August through October, and within the 50-m isobath all along the northern Alaska coast spanning from Point Barrow eastward, during the westward fall migration in September and October (Clarke et al. 2015).

Densities just south of the proposed survey area are likely to be low (Schick et al. 2017); they are also expected to be low throughout the proposed survey area. However, bowhead whales have been tracked near the southern portion of the survey area and likely forage there (Quakenbush et al. 2018; Citta et al. 2018a). Bowhead whales were not reported by vessel-based observers during cruises in the Arctic Ocean north of Utqiaġvik in August–September 2005, July–August 2006, August–September 2009, or August–September 2010 (Haley 2006; Haley and Ireland 2006; Mosher et al. 2009; Beland and Ireland 2010). No bowhead whales were seen during surveys north of the Chukchi Sea between ~72 and ~77°N in September–October 2011 (RPS 2012). However, there are several records of bowhead whales in the OBIS database for 75°N, 154°W, as well as four records at 73.2°N (OBIS 2021). Sekiguchi et al. (2008) reported one sighting of an aggregation of ~30 bowheads during vessel-based operations ~130 km north of Cape Lisburne on 9 August 2007. One bowhead whale that was satellite-tagged in Utqiaġvik on 23 September 2008 traveled 330 km northwest of Utqiaġvik (~73°N; 163°W), south of the proposed survey area, in water ~200 m deep (Quakenbush et al. 2010a). Another whale tagged in late August 2007 traveled northwest (~75°N; 176°W), where water depth was 600 m (Quakenbush et al. 2010a). One whale tagged in the fall of 2009 traveled as far as ~76°N; 179°W, west of the proposed survey area (Quakenbush et al. 2010b). Given the telemetry data (Quakenbush et al. 2010a,b) and OBIS records (OBIS 2021), some bowheads could be encountered during the proposed survey in the Arctic Ocean.

3.3.1.2 Gray Whale (*Eschrichtius robustus*)

Two separate populations of gray whales are recognized in the North Pacific: the eastern North Pacific DPS and western North Pacific (or Korean-Okhotsk) DPS (LeDuc et al. 2002; Weller et al. 2013). However, the distinction between these two populations has been recently debated owing to evidence that whales from the western feeding area also travel to breeding areas in the eastern North Pacific (Weller et al. 2012, 2013; Mate et al. 2015). Thus, it is possible that whales from either the U.S. ESA-listed ***endangered*** Western North Pacific DPS or the delisted Eastern North Pacific DPS could occur near the proposed survey area. Based on communications with NMFS, it is assumed that 0.1% of gray whales could be from the endangered Western North Pacific DPS (NMSF pers. comm. based on Carretta et al. 2019, 2020).

The western population is known to feed in the Okhotsk Sea along the northeast coast of Sakhalin Island (Weller et al. 1999, 2002a, 2008), eastern Kamchatka, and the northern Okhotsk Sea in the summer and autumn (Vladimirov et al. 2008). Winter breeding grounds are not known; however, it has been postulated that wintering areas occur along the south coast of the Korean Peninsula, but it is more likely that they are located in the South China Sea, along the coast of Guangdong province and Hainan (Wang 1984 and Zhu 1998 *in* Weller et al. 2002a; Rice 1998). If migration timing is similar to that of the better-known eastern gray whale, southbound migration probably occurs mainly in December–January and northbound migration mainly in February–April, with northbound migration of newborn calves and their mothers probably concentrated at the end of that period.

Eastern Pacific gray whales breed and calve in the protected waters along the west coast of Baja, California, and the east coast of the Gulf of California from January to April (Swartz and Jones 1981; Jones and Swartz 1984). At the end of the breeding and calving season, most of these gray whales migrate ~8000 km, generally along the west coast, to the main summer feeding grounds in the northern Bering and Chukchi seas (Tomilin 1957; Rice and Wolman 1971; Braham 1984; Nerini 1984; Moore et al. 2003; Bluhm et al. 2007). Most summering gray whales congregate in the northern Bering Sea, particularly off St. Lawrence Island and in the Chirikov Basin (Moore et al. 2000b) and in the southern Chukchi Sea. However, Moore et al. (2003) suggested a decrease in gray whale use of Chirikov Basin, likely as a result of the combined effects of changing currents resulting in altered secondary productivity dominated by lower quality food. The Chirikov Basin and St. Lawrence Island have been described to be feeding BIAs for gray whales from May through November (Ferguson et al. 2015a). The northeastern-most of the recurring gray whale feeding areas is in the northeastern Chukchi Sea southwest of Utqiaġvik (Clarke et al. 1989); this region as well as others in the northeastern Chukchi Sea have also been identified as summer feeding BIAs (Clarke et al. 2015). Areas in the northeastern Chukchi Sea have also been reported as reproduction BIAs during June through September (Clarke et al. 2015). The Chirikov Basin and Bering Strait are also considered a northbound migratory corridor BIA, in particular from June through December (Ferguson et al. 2015a).

Moore et al. (2000a) reported that during the summer, gray whales in the Chukchi Sea were clustered along the shore primarily between Cape Lisburne and Point Barrow and were associated with shallow, coastal shoal habitat. In autumn, gray whales were clustered near shore at Point Hope and between Icy Cape and Point Barrow, and in offshore waters northwest of Point Barrow at Hanna Shoal and southwest of Point Hope. Citta et al. (2018b) also reported concentration areas in the central Chukchi Sea and southwest of Point Barrow during May–November. Similarly, Schick et al. (2017) noted high densities southwest of Point Barrow during summer and early fall, but very low densities near the southern parts of the proposed survey area. Kuletz et al. (2015) also noted hot spots of gray whales in those areas. Based on aerial surveys of nearshore waters of the eastern Chukchi Sea, Thomas et al. (2010) reported that gray whale sighting rates and abundance were greater in the 0–5 km offshore band in 2006, and in the 25–30 km band in 2007 and 2008; they suggested that the difference in distribution may have been attributable to differences in food availability and perhaps ice conditions. Clarke et al. (2016) found that in the northeastern Chukchi Sea, gray whales primarily occur within 95 km from shore, whereas in the southern Chukchi Sea, they occur ~60–115 km

Only a small number of gray whales enter the Beaufort Sea east of Point Barrow. Over the years, ice conditions have become lighter near Utqiaġvik, and gray whales may have become more common. Several gray whale sightings were reported during both vessel-based and aerial surveys in the Beaufort Sea during 2006–2010 (Funk et al. 2011) and by Beland and Ireland (2010) in 2010. Several single gray whales have been seen farther east in the Canadian Beaufort Sea (e.g., Rugh and Fraker 1981), indicating that small numbers must travel through the Alaskan Beaufort during some summers. However, no gray whales were sighted during cruises north of Utqiaġvik in 2002, August–September 2005, July–August 2006, or August–September 2009 (Harwood et al. 2005; Haley 2006; Haley and Ireland 2006; Mosher et al. 2009). Similarly, no gray whales were seen during surveys north of the Chukchi Sea between ~72 and ~77°N in September–October 2011 (RPS 2012). In the OBIS database, there are >1000 gray whale records for the Chukchi Sea and ~30 for the Beaufort Sea; no records were reported north of 73°N (OBIS 2021). Given that most gray whales are typically seen nearshore, and the seismic survey is proposed to occur far offshore, few gray whales, if any, are expected to be in the region at the time of the proposed survey.

NOAA (2021b) has declared an unusual mortality event (UME) for gray whales for 2019–2021, as an elevated number of strandings have occurred along the west coast of North America from Mexico to Alaska since January 2019. As of 31 December 2020, a total of 386 strandings have been reported in 2019 and 2020, including 201 in the U.S. (93 in Alaska); some of the whales were emaciated. UMEs for gray whales were also declared in 1999 and 2000 (NOAA 2021b).

3.3.1.3 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). 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). Humpbacks migrate between summer feeding grounds in high latitudes and winter calving and breeding grounds in tropical waters (Clapham and Mead 1999).

North Pacific humpback whales summer in feeding grounds along the Pacific Rim and in the Bering and Okhotsk seas (Winn and Reichley 1985; Calambokidis et al. 2000, 2001, 2008; Bettridge et al. 2015). Humpbacks winter in four different breeding areas: (1) the coast of Mexico; (2) the coast of Central America; (3) around the main Hawaiian Islands; and (4) in the western Pacific, particularly around the Ogasawara and Ryukyu islands in southern Japan and the northern Philippines (Calambokidis et al. 2008; Bettridge et al. 2015). These breeding areas are recognized as the Mexico, Central America, Hawaii, and Western Pacific DPSs, but feeding areas have no DPS status (Bettridge et al. 2015; NMFS 2016b). There is potential for mixing of the western and eastern North Pacific humpback populations on their summer feeding grounds, but several sources suggest that this occurs to a limited extent (Muto et al. 2020). According to Muto et al. (2020), NMFS is currently reviewing the global humpback whale stock structure in light of the revisions to their ESA listing and identification of 14 DPSs (NMFS 2016b). Individuals that may be encountered in the Arctic Ocean would most likely be from the Hawaii, Mexico, or Western North Pacific DPSs (Calambokidis et al. 2008; Wade 2017). According to Wade (2017), 87% of humpbacks occurring in the Aleutian Islands and Bering Sea are likely from the Hawaii DPS, whereas 11% are from the Mexico DPS, and 2% are from the Western North Pacific DPS.

During summer, most eastern North Pacific humpback whales are on feeding grounds in Alaska, with smaller numbers summering off the U.S. west coast and B.C. (Calambokidis et al. 2001, 2008). Currently, two stocks of humpback whales are recognized as occurring in Alaskan waters. The Central North Pacific Stock occurs from Southeast Alaska to the Alaska Peninsula, and the Western North Pacific Stock occurs from the Aleutians to the Bering Sea and Russia. These two stocks overlap on feeding grounds in the eastern Bering Sea and the western Gulf of Alaska (Muto et al. 2020), where several feeding BIAs have been designated (Ferguson et al. 2015a,b).

In the Bering Sea, humpback whales have been sighted southwest of St. Lawrence Island, in the southeastern Bering Sea, and north of the central Aleutian Islands (Moore et al. 2002; Muto et al. 2020). There have also been sightings in the Chukchi Sea and a single sighting in the Beaufort Sea (Greene et al. 2007; Haley et al. 2010; Funk et al. 2011; Brower et al. 2018). Haley et al (2010) reported three humpback whales during vessel-based surveys in the Chukchi Sea in 2007 and one sighting in 2008. Funk et al. (2011) reported 7 sightings of 11 humpbacks during surveys in 2006–2010. A humpback whale sighting was also made during the 2009 Chukchi Offshore Monitoring in Drilling Area (COMIDA) aerial surveys (Clarke et al. 2011). Greene et al. (2007) reported and photographed a humpback whale cow/calf pair east of Utqiaġvik near Smith Bay in 2007. No humpback whales were reported during cruises in the Arctic Ocean north of Utqiaġvik in August–September 2005, July–August 2006, August–September 2009, and August–September 2010 (Haley 2006; Haley and Ireland 2006; Mosher et al. 2009; Beland and Ireland 2010) or north of the Chukchi Sea between ~72 and ~77°N in September–October 2011 (RPS 2012). There are 56 humpback records in the OBIS database for the Chukchi Sea; no records occurred north of 71°N (OBIS 2021). Humpback whales could occur in the Chukchi Sea and possibly in the Beaufort Sea but would be unlikely to occur in the offshore waters of the proposed survey area in the Arctic Ocean.

3.3.1.4 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 and summer and southward migration in autumn (Stewart and Leatherwood 1985). In the North Pacific, the summer range of the minke whale extends to the Chukchi Sea; in the winter, the whales move south to within 2º of the Equator (Perrin et al. 2018).

The IWC recognizes three stocks of minke whales in the North Pacific: the Sea of Japan/East China Sea, the rest of the western Pacific west of 180ºN, and the remainder of the Pacific (Donovan 1991). Minke whales are relatively common in the Bering Sea and Gulf of Alaska (Brueggeman et al. 1990). Sightings are also thought to be increasing in the Chukchi Sea (Brower et al. 2018). In the far north, minke whales are thought to be migratory, but they are believed to be year-round residents in nearshore waters off west coast of the U.S. (Dorsey et al. 1990).

During vessel-based surveys in the Chukchi Sea during 2006–2010, 48 sightings of 59 minke whales were made (Funk et al. 2011). Brueggeman (2009) and Aerts et al. (2013) reported sightings of single minke whales in the northeastern Chukchi Sea in 2008. Savarese et al. (2010) reported one minke whale in the Beaufort Sea during vessel-based operations in 2007. However, no minke whales were sighted during cruises in the Arctic Ocean north of Utqiaġvik in August–September 2005, July–August 2006, August–September 2009, August–September 2010 (Haley 2006; Haley and Ireland 2006; Mosher et al. 2009; Beland and Ireland 2010) or north of the Chukchi Sea between ~72 and ~77°N in

September–October 2011 (RPS 2012). There are 14 records of minke whales in the OBIS database for the Chukchi Sea; none were reported north of 71°N (OBIS 2021). Minke whales sometimes occur in areas with minimal ice cover, but it is unlikely that they would be encountered during the proposed survey in the Arctic Ocean.

3.3.1.5 Fin Whale (*Balaenoptera physalus physalus*)

The fin whale is widely distributed in all the World's oceans (Gambell 1985), although it is most abundant in temperate and cold waters (Aguilar and García-Vernet 2018). Nonetheless, its overall range and distribution are not well known (Jefferson et al. 2015). A review of fin whale distribution in the North Pacific noted the lack of sightings across pelagic waters between eastern and western winter areas (Mizroch et al. 2009). Fin whales most commonly occur offshore, but can also be found in coastal areas (Jefferson et al. 2015).

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

North Pacific fin whales summer from the Chukchi Sea to California and winter from California southwards (Gambell 1985); they typically do not range into the Alaskan Beaufort Sea or waters of the northern Chukchi Sea. A feeding BIA has been identified in the Bering Sea, with highest densities from June through September (Ferguson et al. 2015a). Four fin whales were sighted in the Chukchi Sea in 2008 (Haley et al. 2010). Funk et al. (2011) reported three sightings of six fin whales during surveys in the Chukchi Sea during 2006–2010. Clarke et al. (2011) also reported a fin whale off Point Lay in 2008 during the COMIDA aerial surveys. Acoustic detections of fin whales in the Chukchi Sea have been made from July–November (Delarue et al. 2013; Tsujii et al. 2016). Fin whales were not recorded during vessel-based or aerial surveys in the Beaufort Sea in 2006–2008 (Funk et al. 2010) and were not sighted during surveys in the Arctic Ocean during August–September 2005, July–August 2006, August–September 2009, and August–September 2010 (Haley 2006; Haley and Ireland 2006; Mosher et al. 2009; Beland and Ireland 2010), or north of the Chukchi Sea between ~72 and ~77°N in September–October 2011 (RPS 2012). There are six records in the OBIS database for the Chukchi Sea (OBIS 2021). Fin whales likely would not be encountered in the proposed survey area in the Arctic Ocean.

3.3.2 Odontocetes

3.3.2.1 Beluga (*Delphinapterus leucas*)

The beluga whale is an arctic and subarctic species with a circumpolar distribution in the Northern Hemisphere, occurring between 50º and 80ºN (Reeves et al. 2002). It is distributed in seasonally ice-covered seas and migrates to warmer coastal estuaries, bays, and rivers in summer for molting (Finley 1982). Of five distinct beluga stocks recognized in Alaska (O'Corry-Crowe et al. 1997), only the Beaufort Sea and Eastern Chukchi Sea stocks could be encountered during the proposed survey. Both stocks of belugas may share common wintering grounds in the pack ice of the central Bering Sea

(O'Corry-Crowe et al. 1997), and a migratory corridor has been described for the eastern Bering Strait with highest densities occurring there from October through May (Ferguson et al. 2015a). A feeding BIA has also been described for coastal waters of the eastern Bering Sea (Ferguson et al. 2015a).

In summer, whales from the Eastern Chukchi Sea stock are known to congregate in Kasegaluk Lagoon; this area has been identified as a feeding BIA (Clarke et al. 2015). However, evidence from a small number of satellite-tagged animals suggests that some of these whales may subsequently range into the Arctic Ocean north of the Beaufort Sea. Suydam et al. (2005) deployed satellite tags on 23 beluga whales captured in Kasegaluk Lagoon in late June and early July 1998–2002. Five of these whales moved far into the Arctic Ocean and into the pack ice to 79–80°N. These and other whales moved to areas as far as 1100 km offshore between Utqiaġvik and the Mackenzie River Delta, spending time in water with 90% ice coverage. A migratory corridor BIA has been identified for this stock from Point Barrow eastward to the U.S./Canada border for the fall migration (Clarke et al. 2015).

Belugas from the Beaufort Sea stock migrate from the Bering Sea through offshore waters of western and northern Alaska and summer in the eastern Beaufort Sea. These regions have been identified as migratory corridor BIAs for this stock; the BIA occurs from the Bering Strait to the Beaufort Sea during the spring migration, and from Point Barrow eastward to the U.S./Canada border for the fall migration (Clarke et al. 2015). Most whales migrate into the Beaufort Sea in April or May, although some whales may pass Point Barrow as early as late March and as late as July (Braham et al. 1984; Ljungblad et al. 1984). Much of the population enters the Mackenzie River estuary for a short period during July–August to molt their epidermis, but they spend most of the summer in offshore waters of the eastern Beaufort Sea, Amundsen Gulf, and more northerly areas (Davis and Evans 1982; Harwood et al. 1996; Richard et al. 2001). Belugas are rarely seen in the central Alaskan Beaufort Sea during the early summer. During late summer and autumn (September–October), most belugas migrate westward far offshore near the pack ice (Frost et al. 1988; Hazard 1988; Clarke et al. 1993; Miller et al. 1999).

Irregular ice conditions during spring and summer can influence the migratory paths to summer areas (O'Corry-Crowe et al. 2016) as well as the fall migration (Hauser et al. 2017). Moore (2000) and Moore et al. (2000a) suggested that beluga whales select deeper slope water independent of ice cover. However, during the westward migration in late summer and autumn, small numbers of belugas are sometimes seen near the north coast of Alaska (e.g., Johnson 1979). The main fall migration corridor of beluga whales is ~100+ km north of the coast. Satellite-linked telemetry data showed that some belugas of this population migrate west considerably farther offshore, as far north as 76–78ºN (Richard et al. 1997, 2001).

Hauser et al. (2014) and Citta et al. (2018b) reported concentration areas of the Eastern Beaufort Sea stock in some regions of the Chukchi Sea and the eastern Beaufort Sea from May–November, and core concentration areas for the Eastern Chukchi Sea stock off the northern coast of Alaska, in particular Barrow Canyon; however, no concentration areas were reported near the proposed survey area, although beluga occurrence was also noted there. Kuletz et al. (2015) also reported hot spots for belugas along the northern coast of Alaska, especially during summer, as well as along the northwest coast of Alaska in the Chukchi Sea. Schick et al. (2017) also showed high summer and early fall density areas off Point Barrow, as well as within the western portion of the proposed survey area, between ~73.5–78°N and 162–168°W. Tagged beluga whales from both stocks have also been reported to occur within the southern portion of the survey area from July to November (Hauser et al. 2014). There are several thousand records of belugas in the OBIS database for the Pacific sector of the Arctic Ocean; 32 occurred between 73 and 74.5ºN, and there are numerous records just to the south of the proposed survey area (OBIS 2021). Belugas were not recorded, however, during arctic cruises in August–September 2005, July–August 2006, August–September 2009, and August–September 2010 (Haley 2006; Haley and Ireland 2006; Mosher et al. 2009; Beland and Ireland 2010), or north of the Chukchi Sea between ~72 and ~77°N in September–October 2011 (RPS 2012). The beluga whale is the most likely cetacean species to occur in the proposed project area.

3.3.2.2 Narwhal (*Monodon monoceros*)

The narwhal has a discontinuous arctic distribution (Hay and Mansfield 1989; Reeves et al. 2002). A large population inhabits Baffin Bay, West Greenland, and the eastern part of the Canadian Arctic archipelago, and much smaller numbers inhabit the Northeast Atlantic/East Greenland area. Narwhals are associated with sea ice. In the spring, as the ice breaks up, they follow the receding ice edge and enter deep sounds and fjords, where they remain during the summer and early fall (Reeves et al. 2002). As the ice reforms, narwhals move to offshore areas in the pack ice (Reeves et al. 2002), living in leads in the heavy pack ice throughout the winter.

There are scattered records of narwhal in Alaskan waters, where the species is considered extralimital (Reeves et al. 2002). George and Suydam (unpubl. ms *in* Muto et al. 2020) reported eight sightings of narwhals in the Chukchi and Beaufort seas from 1989 to 2008 as observed by Alaska Native hunters. Narwhals were not recorded during cruises in the Arctic Ocean during August–September 2005, July–August 2006, August–September 2009, and August–September 2010 (Haley 2006; Haley and Ireland 2006; Mosher et al. 2009; Beland and Ireland 2010), or north of the Chukchi Sea between ~72 and ~77°N in September–October 2011 (RPS 2012). There is one narwhal record in the OBIS database for the Bering Strait (OBIS 2021). Narwhals are unlikely to be encountered during the proposed survey.

3.3.2.3 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 are segregated socially, genetically, and ecologically into three distinct ecotypes: residents, transients, and offshore animals. Killer whales are known to inhabit almost all coastal waters of Alaska, extending from southeast Alaska through the Aleutian Islands and to the Bering Sea (Muto et al. 2020). Killer whales that occur in the Arctic Ocean could be from two stocks: the Alaska Residents, that occur from Southeast Alaska to the Bering Sea; or Gulf of Alaska, Aleutians, and Bering Sea Transients, that occur from Prince William Sound through to the Aleutians and Bering Sea (Carretta et al. 2020; Muto et al. 2020). In the past, Alaska residents were considered to be the same stock as Northern Residents (Muto et al. 2020), but acoustic and genetic data confirmed that these are separate stocks (e.g., Hoelzel et al. 2002; Yurk et al. 2002).

Killer whales have also been sighted in the Chukchi and Beaufort seas, but they are unlikely to occur there regularly (Leatherwood et al. 1986; Lowry et al. 1987). George et al. (1994) reported that a few killer whales are seen at Point Barrow each year. Although little is known about the whales that occur in the Beaufort Sea, they appear to be transient-type whales (Muto et al. 2020). Killer whales were observed predating on belugas in Kotzebue Sound in the southern Chukchi Sea during 2007 (O'Corry-Crowe et al. 2016). Observers onboard industry vessels in the Chukchi Sea recorded two killer whales in 2006 and one killer whale in 2008 (Haley et al. 2010). Another two groups totaling nine killer whales were seen in the eastern Chukchi Sea during surveys in 2008 by Aerts et al. (2013). No killer whales were seen during aerial or vessel surveys in the Beaufort Sea during 2006–2008 (Funk et al. 2010). The killer whale was not sighted during cruises in the Arctic Ocean during August–September 2005, July–August 2006, August–September 2009, and August–September 2010 (Haley 2006; Haley and Ireland 2006; Mosher et al. 2009; Beland and Ireland 2010), or north of the Chukchi Sea between ~72 and ~77°N in

September–October 2011 (RPS 2012). There are 10 killer whale records in the OBIS database for the Bering Strait (2021). Killer whales are unlikely to be encountered during the proposed seismic survey.

3.3.2.4 Harbor Porpoise (*Phocoena phocoena vomerina*)

The harbor porpoise inhabits temperate, subarctic, and arctic waters. It is typically found in shallow water (<100 m) nearshore but is occasionally sighted in deeper offshore water (Jefferson et al. 2015); abundance declines linearly as depth increases (Barlow 1988). In the eastern North Pacific, its range extends from Point Barrow, Alaska, to Point Conception, California. In Alaska, three stocks of harbor porpoise are currently recognized: Southeast Alaska, Gulf of Alaska, and Bering Sea. Only the Bering Sea stock could occur near the proposed survey area. The seasonal movements of harbor porpoise appear to be inshore-offshore, rather than north-south, as a response to the abundance and distribution of food resources (Dohl et al. 1983; Barlow 1988). Genetic testing has also shown that harbor porpoises along the west coast of North America are not migratory and occupy restricted home ranges (Rosel et al. 1995).

During vessel-based surveys in the Chukchi Sea, the harbor porpoise was one of the most abundant cetaceans sighted during summer and fall 2006–2008 (Haley et al. 2010); they were also seen during surveys in the open water seasons of 2008–2010 (Aerts et al. 2013). Point Barrow is the approximate northeastern extent of its regular range (Suydam and George 1992), though there are extralimital records east to the mouth of the Mackenzie River in Canada and sightings in the Beaufort Sea near Prudhoe Bay during aerial surveys in 2006–2008 (Christie et al. 2010; LGL Limited, unpubl. data). Observers onboard industry vessels reported one sighting in the Beaufort Sea in 2006, but none in 2007 or 2008 (Savarese et al. 2010). Harbor porpoises were not recorded during aerial surveys in the Beaufort Sea in 2002–2004 (Monnett and Treacy 2005), nor during cruises in the Arctic Ocean during August–September 2005, July–August 2006, August–September 2009, and August–September 2010 (Haley 2006; Haley and Ireland 2006; Mosher et al. 2009; Beland and Ireland 2010), or north of the Chukchi Sea between ~72 and ~77°N in September–October 2011 (RPS 2012). There are ~10 records for the Chukchi Sea, but none north of 72°N (OBIS 2021). Given that the harbor porpoise is mainly a shallow-water species, no encounters with this species are expected in the far offshore waters where the seismic survey is to occur.

3.3.3 Pinnipeds

3.3.3.1 Pacific Walrus (*Odobenus rosmarus divergens*)

The walrus occurs in moving pack ice over shallow water of the circumpolar arctic coast (King 1983). Walruses are most commonly found near the southern margins of the pack ice as opposed to deep in the pack where few open leads (polynyas) exist to afford access to the sea for foraging (Estes and Gilbert 1978; Fay 1982; Gilbert 1989). Walruses are not typically found in areas of >80% ice cover (Fay 1982). Ice serves as an important mobile platform providing walruses with a place to rest and nurse their young that is safe from predators and near feeding grounds. Walruses typically feed in depths of 10–80 m (Vibe 1950; Fay 1982; Reeves et al. 2002).

The Pacific walrus ranges from the Bering Sea to the Chukchi Sea, occasionally moving into the East Siberian and Beaufort seas. Walruses are migratory, moving south with the advancing ice in autumn and north as the ice recedes in spring (Fay 1981). Jay et al. (2011) reported that walrus have been arriving in the Chukchi Sea earlier and have stayed later into the fall, due to early ice-breakup in the summer and delayed freeze-up during fall. In the summer, most Pacific walruses move to the Chukchi Sea, but several thousand aggregate in the Gulf of Anadyr and in Bristol Bay (Garlich-Miller et al. 2011). Citta et al. (2018b) reported a concentration area for walrus occurrence in the Chukchi Sea off Point Barrow. Similarly, Schick et al. (2017) noted high densities northwest of Point Barrow during summer and early fall, as did Kuletz et al. (2015).

Limited numbers of walruses inhabit the Beaufort Sea during the open water season, and they are considered extralimital east of Point Barrow (Sease and Chapman 1988). The northeast Chukchi Sea west of Utqiaġvik is the northeastern extent of the main summer range of the walrus, and only a few individuals are seen farther east in the Beaufort Sea (e.g., Harwood et al. 2005; Funk et al. 2010). During a survey through the northern Chukchi Sea/Arctic Ocean in August–September 2005, two sightings of a total of seven walruses were made between 71.5 and 73°N, 164ºW, just south of the proposed survey area in water depths <70 m (Haley and Ireland 2006). No walruses were sighted during surveys in the Arctic Ocean during July–August 2006, August–September 2009, or August–September 2010 (Haley 2006; Mosher et al. 2009; Beland and Ireland 2010); however, several sightings were made during surveys between 72 and 76°N during September–October 2002 (Harwood et al. 2005) and September–October 2012 (RPS 2012). Eighty-four walrus were seen just south of the proposed survey area between 72.5 and 73.5°N during September 2018 Navy research activities (U.S. Navy 2019a). There are 384 records in the OBIS database for the central Chukchi Sea (OBIS 2021). Few, if any, walrus are expected to be encountered in the survey area because they occur in pack ice and R/V *Sikuliaq* would avoid ice during the cruise.

3.3.3.2 Bearded Seal (*Erignathus barbatus*)

The bearded seal is associated with sea ice and has a circumpolar distribution, generally south of 80ºN (Jefferson et al. 2015). In waters around Alaska, it occurs over the continental shelves of the Bering, Chukchi, and Beaufort seas and Arctic Ocean. During the open-water period, bearded seals occur mainly in relatively shallow areas, because they are predominantly benthic feeders (Burns 1981). They prefer areas of water no deeper than 200 m (e.g., Harwood et al. 2005). Bearded seals have occasionally been reported to maintain breathing holes in sea ice and broken areas within the pack ice, particularly if the water depth is <200 m. Bearded seals apparently also feed on ice-associated organisms when they are present, and this allows a few bearded seals to live in areas considerably deeper than 200 m.

Seasonal movements of bearded seals are directly related to the advance and retreat of sea ice and to water depth (Kelly 1988; Boveng and Cameron 2013). During winter, most bearded seals in Alaskan waters are found in the Bering Sea. In the Chukchi and Beaufort seas, favorable conditions are more limited, and consequently, bearded seals are less abundant there during winter. Nonetheless, bearded seal vocalizations have been recorded nearly year-round in the Beaufort and Chukchi seas, with peak activity during March–June (MacIntyre et al. 2015). From mid-April to June, as the ice recedes, some of the bearded seals that overwintered in the Bering Sea migrate northward through the Bering Strait. During the summer, they are found near the widely fragmented margin of multi-year ice covering the continental shelf of the Chukchi Sea and in nearshore areas of the central and western Beaufort Sea. In the Beaufort Sea, bearded seals rarely use coastal haulouts.

In some areas, bearded seals are associated with the ice year-round; however, they usually move shoreward into open water areas when the pack ice retreats to areas with water depths greater than 200 m. During the summer, when the Bering Sea is ice-free, the most favorable bearded seal habitat is found in the central or northern Chukchi Sea/Arctic Ocean along the margin of the pack ice. Citta et al. (2018b) reported concentration areas in the Chukchi Sea along the coast of Alaska. Suitable habitat is more limited in the Beaufort Sea where the continental shelf is narrower and the pack ice edge frequently occurs seaward of the shelf and over water too deep for benthic feeding. The preferred habitat in the western and central Beaufort Sea during the open water period is the continental shelf seaward of the scour zone. Nonetheless, Schick et al. (2017) reported high densities off northwestern Alaska in the Chukchi Sea as well as in the nearshore waters of the Beaufort Sea.

Vessel surveys in the Arctic Ocean have reported much lower percentages of bearded compared to ringed seals during cruises in the Arctic Ocean in 2005, 2006, and 2010 (Haley 2006; Haley and Ireland 2006; Beland and Ireland 2010). During surveys north of the Chukchi Sea during September–October 2011, bearded seals were only recorded between 72 and 73°N (RPS 2012). However, a sighting of two bearded seals was made in deep water as far north as 78.5°N, 149.8°W during August 2010 (Beland and Ireland 2010). Two bearded seals were sighted in the Arctic Ocean during August–September 2009; one seal was seen at 80.8°N, 151.9°W and the other at 80.9°N, 147°W (Mosher et al. 2009). Boveng and Cameron (2013) also reported sightings of tagged bearded seals near the southern portion of the proposed survey area, north of 70°N. In the OBIS database, there are 28 records between 73 and 79°N for the Pacific sector of the Arctic Ocean; in addition, there are several thousand records for the Beaufort Sea and several hundred records for the Chukchi Sea (OBIS 2021). Thus, bearded seals could be encountered in the proposed survey area, but they are more likely to occur in the shallower southern portion.

NOAA (2021c) declared a UME for Alaska Ice Seals in 2019 for the Chukchi and Beaufort seas, which is still active; since June 2018, 94 bearded seals have been found stranded, as well as 96 unidentified ice seals.

3.3.3.3 Spotted Seal (*Phoca largha*)

The spotted seal (also known as largha seal) occurs in the Beaufort, Chukchi, Bering, and Okhotsk seas, and south to the northern Yellow Sea and western Sea of Japan (Shaughnessy and Fay 1977). During summer, spotted seals are found primarily in the Bering and Chukchi seas, but some range into the Beaufort Sea (Rugh et al. 1997; Lowry et al. 1998). At this time of year, spotted seals haul out on land part of the time, but also spend extended periods at sea. The seals are commonly seen in bays, lagoons and estuaries, but also range far offshore as far north as 71ºN (Boveng et al. 2009). In summer, they are rarely seen on the pack ice, except when the ice is very near to shore. As the ice cover thickens with the onset of winter, spotted seals leave the northern portions of their range and move into the Bering Sea (Lowry et al. 1998).

Spotted seals have been sighted during open-water seismic programs and barge operations in the Alaskan Beaufort Sea (Moulton and Lawson 2002; Greene et al. 2007; Savarese et al. 2010) and during vessel-based seismic surveys and aerial surveys in the Chukchi Sea during 2006–2008 (Brueggeman 2009; Funk et al. 2010). Citta et al. (2018b) reported concentration areas for spotted seals in the Chukchi Sea along the coast of Alaska. One spotted seal was seen just south of the proposed survey area during September 2018 Navy research activities (U.S. Navy 2019a). Spotted seals were also sighted around 72°N during surveys in September–October 2011 (RPS 2012). Boveng et al. (2017) noted their likely occurrence near the southern portion of the proposed survey area. However, no spotted seals were recorded on arctic cruises during August–September 2005, July–August 2006, August–September 2009, or August–September 2010 (Haley 2006; Haley and Ireland 2006; Mosher et al. 2009; Beland and Ireland 2010). There are 12 records between 72 and 73°N in the OBIS database for the Pacific sector of the Arctic Ocean, in addition to ~100 records for the Chukchi Sea and ~20 records for the Beaufort Sea. Spotted seals are unlikely to occur in the proposed survey area although some spotted seals could be encountered during transit periods. Since June 2018, 51 spotted seals have been found stranded (NOAA 2021c).

3.3.3.4 Ribbon Seal (*Histriophoca fasciata*)

The ribbon seal is found along the pack-ice margin in the southern Bering Sea during late winter and early spring, and it moves north as the pack ice recedes during late spring to early summer (Burns 1970; Burns et al. 1981). Little is known about ribbon seal summer and fall distribution, but a review of sightings during the summer suggested that they move into the southern Chukchi Sea (Kelly 1988). Boveng et al. (2013) reported that the known distribution extends into the Arctic Ocean to ~79°N. During a satellite telemetry program, a number of ribbon seals tagged in the Bering Sea in May had moved to the Chukchi Sea by July (Cameron et al. 2009), and Boveng et al. (2017) noted their likely occurrence near the southern portion of the proposed survey area. However, ribbon seals appeared to be relatively rare in the northern Chukchi Sea during vessel and aerial surveys in summer and fall of 2006–2008 (Brueggeman 2009; Funk et al. 2010). Nonetheless, Aerts et al. (2013) reported six ribbon seals during open-water surveys in the northwestern Chukchi Sea. Ribbon seals do not normally occur in the Beaufort Sea, although three ribbon seal sightings were reported during vessel-based surveys in the Beaufort Sea in 2008 (Savarese et al 2010). No ribbon seals were recorded on cruises in the Arctic Ocean during August–September 2005, July–August 2006, August–September 2009, and August–September 2010 (Haley 2006; Haley and Ireland 2006; Mosher et al. 2009; Beland and Ireland 2010), or north of the Chukchi Sea between ~72 and ~77°N in September–October 2011 (RPS 2012). There is one record in the OBIS database for the Chukchi Sea, three for the Bering Strait, and two for the Canadian Beaufort Sea (OBIS 2021). It is possible that ribbon seals could be encountered in the proposed survey area.

3.3.3.5 Ringed Seal (*Phoca hispida hispida*)

The ringed seal has a circumpolar distribution and occurs in all seas of the Arctic Ocean (King 1983). Ringed seals are closely associated with ice, and in summer they often occur along the receding ice edges or farther north in the pack ice. During winter, ringed seals occupy landfast ice and offshore pack ice, maintaining breathing holes in the ice and occupying lairs in accumulated snow where they give birth and nurse their pups (Smith and Stirling 1975). In winter and spring, the highest densities of ringed seals are found on stable shorefast ice. However, in some areas where there is limited fast ice but wide expanses of pack ice, including the Beaufort Sea, Chukchi Sea, and Baffin Bay, total numbers of ringed seals on pack ice may exceed those on shorefast ice (Burns 1970; Stirling et al. 1982; Finley et al. 1983). During the summer, ringed seals are known to undertake long-distance movements when sea ice extent is minimal (Kelly et al. 2010b; Martinez-Bakker et al. 2013).

Ringed seals are year-round residents in the northern Chukchi and Beaufort seas and are the most frequently encountered seal species in the area. Some ringed seals are known to migrate from the Beaufort Sea to the Chukchi Sea during fall (Harwood et al. 2012). There are core concentration areas in the Chukchi and Beaufort seas, but none were reported for the southern portion of the proposed survey area, although occurrence was reported there (Citta et al. 2018b).

In the Chukchi Sea, the ringed seal was the most abundant seal species sighted during vessel-based surveys in 2006–2008, with densities up to 0.129/km^2 in the fall (Haley et al 2010). In the Beaufort Sea, the ringed seal was also the most abundant seal species during similar fall vessel-based surveys, with densities up to 0.103/km^2 (Savarese et al. 2010). Many unidentified seals during these surveys may have also been ringed seals, thus actual densities may have been higher. In the Arctic Ocean, the ringed seal was also the most frequently sighted marine mammal species during cruises in August–September 2005 (Haley and Ireland 2006), July–August 2006 (Haley 2006), August–September 2009 (Mosher et al. 2009), or August–September 2010 (Beland and Ireland 2010). Ringed seals were also seen during surveys north of the Chukchi Sea between ~75 and ~77°N in September–October 2011 (RPS 2012). Von Duyke et al.

(2020) reported movements of ringed seals through the southern survey area during summer/fall. In the OBIS database, there are nearly 200 records between 72 and 82°N for the Pacific sector of the Arctic Ocean, including 99 sightings made during the aforementioned surveys, and an additional ~260 records for the Chukchi Sea, and nearly 4000 records for the Beaufort Sea (OBIS 2021). The ringed seal is the marine mammal most likely to be encountered during the proposed survey. Since June 2018, 74 ringed seals have been found stranded (NOAA 2021c).

3.3.4 Marine Fissiped

3.3.4.1 Polar Bear (*Ursus maritimus*)

The polar bear has a circumpolar distribution throughout the Northern Hemisphere (Amstrup et al. 1986); it occurs in relatively low densities throughout most ice-covered areas (DeMaster and Stirling 1981). In addition to the U.S. MMPA, the polar bear is protected by the International Agreement on the Conservation of Polar Bears, ratified in 1976 by Canada, Denmark, Norway, Russia (former USSR), and the U.S. Article II of the agreement states, "Each contracting party…shall manage polar bear populations in accordance with sound conservation practices based on the best scientific data."

Polar bears are divided into 19 relatively distinct populations or management units although there may be overlap of some individuals among populations (Aars et al. 2006; USFWS 2008a; IUCN/SSC PBSG 2019). Individuals from four populations could occur in the proposed survey area: Arctic Basin (unknown population size); Chukchi Sea population (~2937 bears), from most of the Chukchi Sea and the northern Bering Sea; Southern Beaufort Sea population (~907 individuals), ranging from the Baillie Islands, Canada, to near Point Lay, Alaska; and the Northern Beaufort Sea population (~980 polar bears), located in Canadian waters primarily north of the Southern Beaufort Sea and extending into Amundsen Gulf (IUCN/SSC PBSG 2019). IUCN/SSC PBSG (2019) reported the Northern and Southern Beaufort Sea populations as likely decreasing, the Chukchi Sea population as likely stable over one generation, and the Arctic Basin population as data deficient. Data from tracking studies indicate wide-ranging movements of individual bears and overlap among polar bear populations (Garner et al. 1990; Amstrup 1995; Durner and Amstrup 1995).

Polar bears usually forage in areas where there are high concentrations of ringed seals which is their primary prey, and bearded seals (Larsen 1985; Stirling and McEwan 1975). This includes areas of landfast ice, as well as moving pack ice. They typically range as far north as 88°N (Ray 1971; Durner and Amstrup 1995) where the population thins dramatically. However, polar bears have been observed across the Arctic, including close to the North Pole (van Meurs and Splettstoesser 2003). During a cruise in the Arctic Ocean in August–September 2005, there were 21 sightings of 27 polar bears, most between ~80 and 82ºN with one at ~87ºN (Haley and Ireland 2006). During a cruise in the Arctic Ocean in July–August 2006, there were three sightings of nine polar bears at ~73 and 78ºN, all on ice (Haley 2006). During a cruise in the Arctic Ocean in August–September 2009, there were nine sightings of 11 polar bears between ~79 and 82ºN (Mosher et al. 2009). Sixteen polar bears were seen on the ice during a seismic survey in the Arctic Ocean in August–September 2010, including five sightings of seven polar bears between 74 and 78ºN (Beland and Ireland 2010). Several sightings were made between 73 and 75°N during surveys in the Pacific sector of the Arctic Ocean during August–October 2002 (Harwood et al. 2005). In addition, three polar bears were seen within the proposed survey area, four polar bears were spotted just south of the proposed survey area at ~73°N, and another three polar bears were sighted swimming in open water adjacent to the proposed survey area at 74.6°N, 146.2°W during September–October Navy research activities in 2018–2019 (U.S. Navy 2019a). In the OBIS database, there are 224 records in the Pacific sector of the Arctic Ocean between 72 and 79°N, as well as an additional ~160 for the Chukchi Sea and

~800 for the Beaufort Sea (OBIS 2021). Few, if any, polar bears are expected to be encountered in the proposed survey area as R/V *Sikuliaq* would avoid ice during the cruise.

3.4 Seabirds

It is unlikely that any ESA-listed seabirds would occur within the proposed survey area. However, three seabird species that are listed under the U.S. ESA could be encountered just south of the proposed project area or during vessel transit off the coast of Alaska. The ***threatened*** spectacled eider (*Somateria fischeri*) travels west along the arctic coast after breeding across the Arctic Coastal Plain (ACP) of northern Alaska. The ***threatened*** Steller's eider (*Polysticta stelleri*) also breeds on the ACP and moves to marine habitats after breeding; it occurs in much lower densities than spectacled eiders and would be even less likely to be encountered. The ***endangered*** short-tailed albatrosses (*Phoebastra albatrus*) ranges over much of the North Pacific following breeding, concentrating along continental shelf edges.

3.4.1 Spectacled Eider

The spectacled eider is a medium-sized sea duck that breeds along coastal areas of western and northern Alaska and eastern Russia and winters in the Bering Sea (Petersen et al. 2000). Three breeding populations have been described: one in the Yukon-Kuskokwim (Y-K) Delta in western Alaska, a second on the North Slope of Alaska, and the third in northeastern Russia. The spectacled eider was listed as a ***threatened*** species because of declines in the breeding population in the Y-K delta (Stehn et al. 1993; Ely et al. 1994). The North Slope spectacled eider population seems to be stable since 1992 (Larned et al. 2009).

Both marine and terrestrial (for males in particular) routes are used during migration (Troy 2003). Males leave the breeding grounds along the coastal plain earlier than females. Male and female spectacled eiders have been documented migrating west along the Alaska coast as far as 24 and 40 km offshore, respectively (TERA 1999). Results from a recent satellite transmitter tracking identified heavily used areas during post-breeding dispersal and molt, including the eastern Chukchi Sea within 70 km of the Alaskan coast, and the eastern and southern portions of Norton Sound; both areas are used from early July–October (Sexson et al. 2014, 2016). There are 11 OBIS records for the Chukchi Sea, as far north as 70.2°N, 162.6°W. Although spectacled eiders are unlikely to occur within the proposed survey area, they could be encountered along the vessel's transit route.

3.4.2 Steller's Eider

Steller's eiders breed across coastal eastern Siberia and the ACP of Alaska. A smaller population also breeds in western Russia and winters in northern Europe (Fredrickson 2020). Steller's eiders were formerly common breeders in the Y-K delta, but numbers there declined drastically, and Steller's eider is now apparently rare or extirpated as a breeding species on the Y-K delta (Kertell 1991; Flint and Herzog 1999). Although Steller's eiders may breed in a relatively large area of the ACP as far east as the Prudhoe Bay area, densities are low. The highest densities are reported near Barrow; the largest population, located in eastern Russia, may number >128,000 birds (Hodges and Eldridge 2001). Steller's eiders have been observed east of Barrow in the Prudhoe Bay area where they are considered rare (TERA 1997).

After the breeding season Steller's eiders move to nearshore marine habitats, using lagoon systems and coastal bays along the coast of Alaska to molt (USFWS 2002). The young Steller's eiders hatch in late June. Male departure from the breeding grounds begins in late June or early July. Females that fail in breeding attempts may remain in the Barrow area into late summer. Females and fledged young depart the breeding grounds on a molt migration in early to mid-September. Individuals from breeding sites on the

ACP head southwest, pass through the Bering Strait, and head to molting sites in the southeast Bering Sea (Martin et al. 2015). The majority (95%) of stop-over locations en-route are within 5 km of the coastline. However, some individuals occasionally use routes far offshore. Their destinations are five molting sites from Nunavik Island to the Alaskan Peninsula. Birds are present at these molting sites as early as late August to as late as early October. Steller's eiders could occur along the proposed vessel transit route. However, there are no records for the proposed survey area in the OBIS database (OBIS 2021).

3.4.3 Short-tailed Albatross

Historically, this species was once the most abundant albatross in the North Pacific, breeding in the western North Pacific Ocean on islands off the coast of Japan. However, the short-tailed albatross was driven to near extinction during the last century by feather hunters at the breeding colonies. In addition, the breeding grounds of the remaining birds were threatened by volcanic eruptions in the 1930s; this species was believed to be extinct in 1949 until it was rediscovered in 1951 (BirdLife International 2021). However, this population is increasing, and the most recent population estimate is 4200 individuals (Birdlife International 2021). Currently, nearly all short-tailed albatrosses breed on two islands off the coast of Japan: Torishima and Minami-kojima (USFWS 2008b; BirdLife International 2021). Its marine range occurs throughout the northern Pacific Ocean, but the highest densities are found in upwelling areas off Japan (during the breeding season, i.e., December to May), eastern Russia, and Alaska, including the Aleutians (Piatt et al. 2006; Suryan et al. 2007). They are considered a continental shelf-edge specialist (Piatt et al. 2006; Orben et al. 2018). Current threats to this population include volcanic activity on Torishima, commercial fisheries, and pollutants (USFWS 2008b).

After the breeding season, short-tailed albatrosses roam much of the North Pacific Ocean; females spend more time offshore from Japan and Russia, while males and juveniles spend more time around the Aleutian Islands and Bering Sea (Suryan et al. 2007). The results of a tracking study suggest that a large proportion of fledglings reach the Bering Sea during the summer of their fledging year (Orben et al. 2018). Post-breeding dispersal occurs from April through November (Suryan et al. 2007; USWFS 2008b; Orben et al. 2018). Short-trailed albatrosses, particularly juveniles, start appearing in the Aleutian Islands and Bering Sea as early as June (USFWS 2008b), but most birds travel to the Aleutians in autumn (Suryan et al. 2006; Orben et al. 2018). In the Bering Sea, these birds concentrate south of St. Matthew Island and in the southeast (Suryan et al. 2006). This species was sighted in the eastern Chukchi Sea in August 2012 (Day et al. 2013b). Although there are numerous OBIS records for the Bering Sea, there are none for the Chukchi Sea. Short-tailed albatross are unlikely to occur within the proposed study area, but could be encountered during the vessel transit.

3.5 Fish and Marine Invertebrates of Concern, Essential Fish Habitat, and Habitat Areas of Particular Concern

The term "species" under the ESA includes species, subspecies, and, for vertebrates only, DPSs or "evolutionarily significant units (ESUs)"; for Pacific salmon, ESUs are essentially equivalent to DPSs for the purpose of the ESA. Although Alaskan fish populations are not listed under the ESA, the Alaska Department of Fish and Game (ADF&G 2021) has listed Chinook (*Oncorhynchus tshawytscha*), chum salmon (*O. keta*), and sockeye salmon (*O. nerka*), as stocks of concern. In addition, there are several ESA-listed salmon stocks that spawn on the west coast of the Lower 48 U.S. that could potentially occur in Alaskan waters during the marine phases of their life cycles, including various ESUs of Chinook, sockeye, chum, and coho salmon (*O. kisutch*). In addition to the aforementioned species, the pink salmon (*O.*

gorbuscha), which is not ESA-listed, could also occur within the proposed survey area and/or during transit to and from the area. There is no critical habitat for fish or marine invertebrate species in Alaska.

Chum salmon spawn between June and January in the Yukon, Canada, in tributaries of the Yukon River which drain into the Chukchi Sea; most spawning ends in November. Chum salmon fry do not overwinter in streams but will out-migrate to the sea as juveniles primarily between April and May (NPFMC 2018). Chinook salmon have also been found to spawn in the Yukon River at the northern edge of their range. One of the largest spawning areas in North America for sockeye salmon occurs in Bristol Bay in the Bering Sea in late July; however, spawning can also take place north of the Bering Strait, in the southern Chukchi Sea. Juveniles emerge as fry between April to June, with peaks in mid-May, and enter the open ocean in late June during their first summer (NPFMC 2018). In Alaska, coho salmon occur as far north as Point Hope on the eastern Chukchi Sea, but they have also been found within the Yukon River drainage system. Juveniles migrate to sea in the spring generally into the North Pacific Ocean and Bering Sea (NPFMC 2018). Pink salmon spawn in coastal streams as far north as the Bering Strait (NPFMC 2018).

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 2017). 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. EFH has been designated for several life history stages of Arctic cod (*Boreogadus saida*), Saffron cod (*Eleginus gracilis*), and snow crab (*Chionoecetes opilio*) in the U.S. Arctic FMP (Table 6, Fig. 2). There is also EFH for various life history stages of five different salmonids within the Chukchi and Beaufort seas (Table 6). However, only Arctic cod EFH occurs within the southern-most portion of the proposed survey area (Fig. 2). Habitat areas of particular concern (HAPC) is a subset of EFH that provides important ecological functions or is especially vulnerable to degradation (NOAA 2017). There are no HAPCs in Alaskan waters north of the Bering Sea.

TABLE 6. Species with Essential Fish Habitat (EFH) in marine waters within the Chukchi and Beaufort seas (NFPMC 2009, 2018; NOAA 2020, 2021d).

Species	Eggs	Larvae	Marine Juvenile	Marine Immature	Early Juvenile	Late Juvenile	Adult
Arctic cod^	✓[1]	✓[1]	N.A.	N.A.	✓	✓	✓
Saffron cod	-	-	N.A.	N.A.	-	✓	✓
Snow crab	✓	-	N.A.	N.A.	-	✓	✓
Pink salmon	*	*	✓	N	N.A.	N.A.	✓
Chum salmon	*	*	✓	✓	N.A.	N.A.	✓
Sockeye salmon	*	*	✓	✓	N.A.	N.A.	✓
Chinook salmon	*	*	✓	✓	N.A.	N.A.	✓
Coho salmon	*	*	✓	N	N.A.	N.A.	✓

- Information currently unavailable. ✓ = present. N = not present. N.A. = not applicable. [1] Loggerwell et al. (2015).
* Salmon egg and larval life stages not included as they occur in freshwater. ^Species with EFH in survey area.

3.6 Fish Assemblages and Fisheries

There are 107 fish species in the Beaufort Sea, including such species as salmon, herring, cod, pollock, halibut, flounders, eelpout, sculpins, and sharks (FishBase 2021). Within the Chukchi Sea, Russian datasets during 1995–2010 have noted 110 species belonging to 68 genera, 26 families, and 11 taxonomic orders. Of these fish communities, sculpins, eelpouts, flounders, shannies, poachers, and salmon dominate (Datsky 2015). A study conducted during 2008–2010 in the Statoil, Klondike, and Burger areas near Hanna Shoal in the northeast Chukchi Sea found that the zooplankton community was represented by 80 taxa and consisted of copepods, appendicularians, arrow worms, hydrozoans, scyphozoans, pteropds, shrimp, and various meroplankton, with copepods, appendicularians, and meroplankton constituting the highest biomass (Day et al. 2013a). Data from the same study showed that the demersal fish community in the northeastern Chukchi Sea is made up of circumpolar species such as Arctic cod, Arctic staghorn sculpin (*Gymnocanthus tricuspis*), and some subarctic species from the northern Bering Sea such as Bering flounder (Day et al. 2013a). Fish surveys conducted during 2007–2012 in the Beaufort and Chukchi seas found that Arctic cod dominated bottom trawls along the shelf of the Beaufort Sea, and salmonids were found almost exclusively in the surface waters of the shelf of the Chukchi Sea, whereas Arctic cod and capelin were found throughout the area (Logerwell et al. 2015). Arctic cod eggs, larvae, and juveniles have been found in ichthyoplankton trawls along the shelves of the Beaufort and Chukchi seas and were found in the highest abundance of all species, which suggests that Arctic cod may use these areas for spawning and larval development (Logerwell et al. 2015). The shelf of the Chukchi Sea was also found to host a large number of flatfish species such as Bering flounder (*Hippoglossoides robustus*) and yellowfin sole (*Limanda aspera*) (Logerwell et al. 2015). Arctic cod and Arctic char (*Salvelinus alpinus*) are ecologically important species as they play critical roles in both pelagic and demersal food webs; they are key prey species for marine mammals such as narwhals, belugas, and ringed seals, and marine-associated seabirds (Harwood et al. 2015; Logerwell et al. 2015; Forster et al. 2020). Other species found in the survey area that are important contributors to food webs include capelin (*Mallotus catervius*), saffron cod (*Eleginus gracilis*), Bering flounder, yellowfin sole, and longhead dab (*Limanda proboscidea*), as well as multiple sculpin, eelpout, blenny, and shanny species (Forster et al. 2020).

The North Pacific Fisheries Management Council (NPFMC), the managing body for Alaskan fisheries, approved the Fishery Management Plan for Fish Resources of the Arctic Management Area (Arctic FMP) in 2009 which closed the U.S. Arctic to commercial fishing and so provides a unique opportunity for implementing a precautionary management strategy for Arctic fish stocks (NPFMC 2009; Forster et al. 2020). The Arctic FMP covers the Arctic U.S. EEZ waters offshore Alaska, known as the Artic Management Area. This area is defined as all marine waters in the U.S. EEZ of the Chukchi and Beaufort seas and from 3 n.mi. offshore the coast of Alaska (NPFMC 2021). All of the federal waters of the Arctic U.S. are closed to commercial fishing for any species of finfish, molluscs, crustaceans, and all forms of marine animal and plant life. Subsistence or recreational fisheries, as well as salmonid fisheries are not regulated by the Arctic FMP (NPFMC 2009, 2021).

There is likely very little, if any, commercial fishing within the survey area. Most of the species that are commonly registered in Russian fishing gear within the western Chukchi Sea, include commercial species (Datsky 2015) such as snow crab (Hunt et al. 2013). According to Sea Around Us (2021), fisheries landings within the U.S. Alaskan/Arctic EEZ for 1950–2015 mainly consisted of chum salmon, followed by whitefishes, sheefish (*Stenodus leucichthys*), and Dolly Vardon (*Salvelinus malma*). Some recreational and subsistence fishing occurs within the U.S. Arctic FMP, but is unlikely to occur as far north as the proposed survey area. In the Chukchi Sea, fisheries occur primarily for local consumption, and include 15 species, such as chum salmon and inconnu/sheefishes (Hunt et al. 2013; NPFMC 2009).

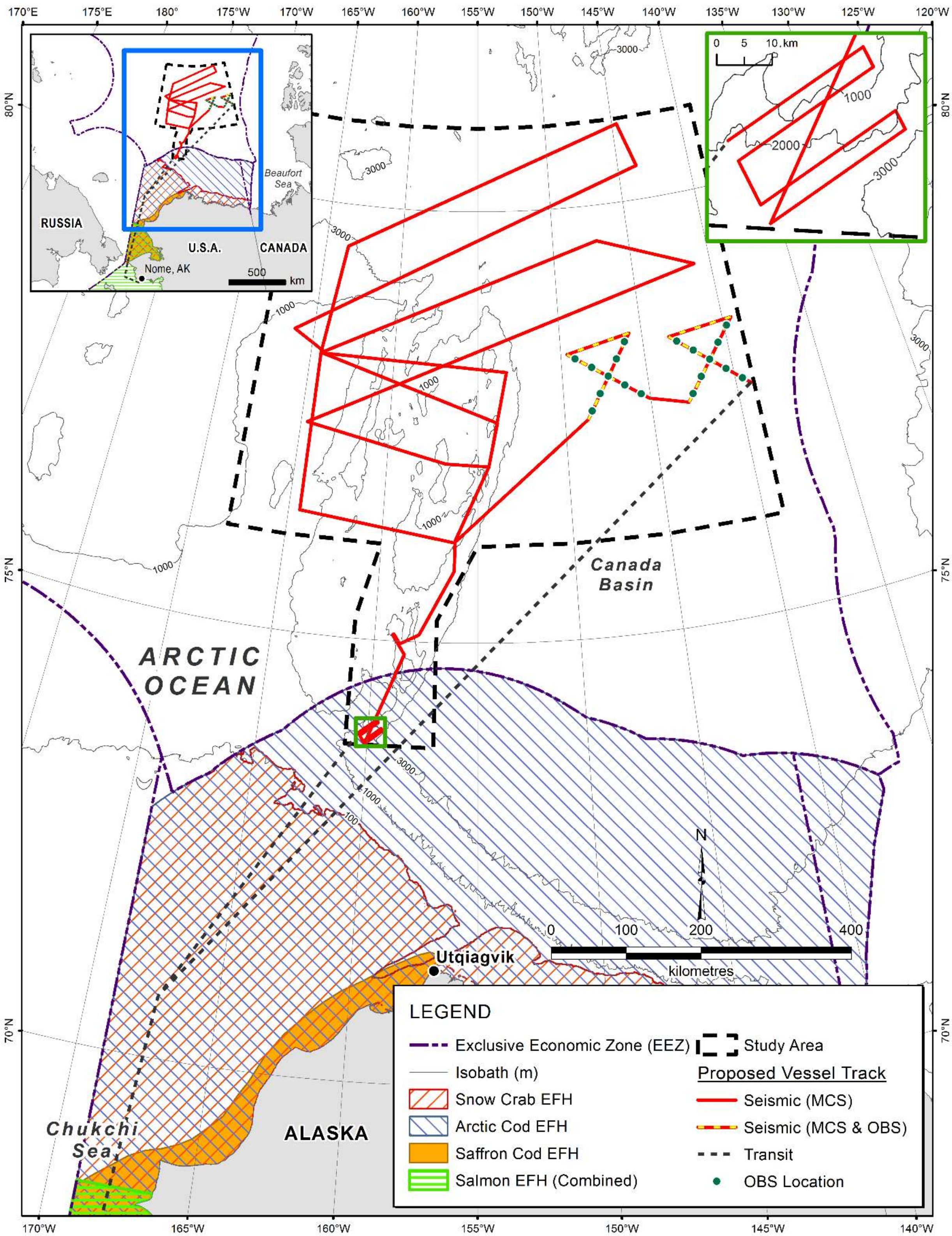

FIGURE 2. Essential Fish Habitat (EFH) within the Arctic FMP area in relation to the proposed surveys in the Arctic Ocean.

IV ENVIRONMENTAL CONSEQUENCES

4.1 Proposed Action

4.1.1 Direct Effects on Marine Mammals 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 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 can also be found in the PEIS. This section also includes estimates of the numbers of marine mammals that could be affected by the proposed seismic surveys. A description of the rationale for NSF's estimates of the numbers of individuals exposed to received sound levels ≥160 dB re 1 μPa_{rms} is also provided.

4.1.1.1 Summary of Potential Effects of Airgun Sounds

As noted in the PEIS (§ 3.6.4.3, § 3.7.4.3, § 3.8.4.3), the effects of sounds from airguns could include one or more of the following: tolerance, masking of natural sounds, behavioral disturbance, and at least in theory, temporary or permanent hearing impairment, or non-auditory physical or physiological effects (Richardson et al. 1995; Gordon et al. 2004; Nowacek et al. 2007; Southall et al. 2007; Erbe 2012; Peng et al. 2015; Erbe et al. 2016; Kunc et al. 2016; National Academies of Sciences, Engineering, and Medicine 2017; Weilgart 2017a; Halliday et al. 2020). 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). Although Hastie et al. (2019) reported that the impulsive nature of sound is range-dependent, becoming less harmful over distance from the source, Martin et al. (2020) noted that sound retains its impulsive character at SPLs above the effective quiet threshold. TTS is not considered an injury (Southall et al. 2007; Le Prell 2012). Rather, the onset of TTS has been considered an indicator that, if the animal is exposed to higher levels of that sound, physical damage is ultimately a possibility. Nonetheless, research has shown that sound exposure can cause cochlear neural degeneration, even when threshold shifts and hair cell damage are reversible (Kujawa and Liberman 2009; Liberman et al. 2016). These findings have raised some doubts as to whether TTS should continue to be considered a non-injurious effect (Weilgart 2014; Tougaard et al. 2015, 2016). Although the possibility cannot be entirely excluded, it is unlikely that the proposed surveys would result in any cases of temporary or permanent hearing impairment, or any significant non-auditory physical or physiological effects. If marine mammals encounter a survey while it is underway, some behavioral disturbance could result, but this would be localized and short-term.

Tolerance.—Numerous studies have shown that pulsed sounds from airguns are often readily detectable in the water at distances of many kilometers (e.g., Nieukirk et al. 2012). Several studies have shown that marine mammals at distances more than a few kilometers from operating seismic vessels often show no apparent response. That is often true even in cases when the pulsed sounds must be readily audible to the animals based on measured received levels and the hearing sensitivity of that mammal group. Although various baleen and toothed whales, and (less frequently) pinnipeds have been shown to react behaviorally to airgun pulses under some conditions, at other times mammals of all three types have shown no overt reactions. The relative responsiveness of baleen and toothed whales are quite variable.

***Masking*.—**Masking effects of pulsed sounds (even from large arrays of airguns) on marine mammal calls and other natural sounds are expected to be limited, although there are few specific data on this. Because of the intermittent nature and low duty cycle of seismic pulses, animals can emit and receive sounds in the relatively quiet intervals between pulses. However, in exceptional situations, reverberation occurs for much or all of the interval between pulses (e.g., Simard et al. 2005; Clark and Gagnon 2006), which could mask calls. Situations with prolonged strong reverberation are infrequent. However, it is common for reverberation to cause some lesser degree of elevation of the background level between airgun pulses (e.g., Gedamke 2011; Guerra et al. 2011, 2016; Klinck et al. 2012; Guan et al. 2015), and this weaker reverberation presumably reduces the detection range of calls and other natural sounds to some degree. Guerra et al. (2016) reported that ambient noise levels between seismic pulses were elevated as a result of reverberation at ranges of 50 km from the seismic source. Based on measurements in deep water of the Southern Ocean, Gedamke (2011) estimated that the slight elevation of background levels during intervals between pulses reduced blue and fin whale communication space by as much as 36–51% when a seismic survey was operating 450–2800 km away. Based on preliminary modeling, Wittekind et al. (2016) reported that airgun sounds could reduce the communication range of blue and fin whales 2000 km from the seismic source. Kyhn et al. (2019) reported that baleen whales and seals were likely masked over an extended period of time during four concurrent seismic surveys in Baffin Bay, Greenland. Nieukirk et al. (2012), Blackwell et al. (2013), and Dunlop (2018) also noted the potential for masking effects from seismic surveys on large whales.

Some baleen and toothed whales are known to continue calling in the presence of seismic pulses, and their calls usually can be heard between the pulses (e.g., Nieukirk et al. 2012; Thode et al. 2012; Bröker et al. 2013; Sciacca et al. 2016). Cerchio et al. (2014) suggested that the breeding display of humpback whales off Angola could be disrupted by seismic sounds, as singing activity declined with increasing received levels. In addition, some cetaceans are known to change their calling rates, shift their peak frequencies, or otherwise modify their vocal behavior in response to airgun sounds (e.g., Di Iorio and Clark 2010; Castellote et al. 2012; Blackwell et al. 2013, 2015; Thode et al. 2020). The hearing systems of baleen whales are undoubtedly more sensitive to low-frequency sounds than are the ears of the small odontocetes that have been studied directly (e.g., MacGillivray et al. 2014). The sounds important to small odontocetes are predominantly at much higher frequencies than are the dominant components of airgun sounds, thus limiting the potential for masking. In general, masking effects of seismic pulses are expected to be minor, given the normally intermittent nature of seismic pulses.

***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. Some studies have attempted modeling to assess consequences of effects from underwater noise at the population level (e.g., King et al. 2015; Costa et al. 2016a,b; Ellison et al. 2016; Harwood et al. 2016; Nowacek et al. 2016; Farmer et al. 2017). Other studies have noted the importance of taking into account the behavior, ecology, and seasonal variation in distribution when considering the effects of exposure of airgun sounds on marine mammals (e.g.,; Hückstädt et al. 2020; Gallagher et al. 2021).

Given the many uncertainties in predicting the quantity and types of impacts of noise on marine mammals, it is common practice to estimate how many marine mammals would be present within a particular distance of industrial activities and/or exposed to a particular level of industrial sound. In most cases, this approach likely overestimates the numbers of marine mammals that would be affected in some biologically important manner. The sound criteria used to estimate how many marine mammals could be disturbed to some biologically important degree by a seismic program are based primarily on behavioral observations of a few species. Detailed studies have been done on humpback, gray, bowhead, and sperm whales. Less detailed data are available for some other species of baleen whales and small toothed whales, but for many species, there are no data on responses to marine seismic surveys.

Baleen Whales

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

Responses of *humpback whales* to seismic surveys have been studied during migration, on summer feeding grounds, and on Angolan winter breeding grounds; there has also been discussion of effects on the Brazilian wintering grounds. Off Western Australia, avoidance reactions began at 5–8 km from the array, and those reactions kept most pods ~3–4 km from the operating seismic boat; there was localized displacement during migration of 4–5 km by traveling pods and 7–12 km by more sensitive resting pods of cow-calf pairs (McCauley et al. 1998, 2000). However, some individual humpback whales, especially males, approached within distances of 100–400 m.

Dunlop et al. (2015) reported that migrating humpback whales in Australia responded to a vessel operating a 20 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). 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). However, some individuals did not show avoidance behaviors even at levels as high as 160 to 170 dB re 1 $\mu Pa^2 \cdot s$ (Dunlop et al. 2018). Dunlop et al. (2020) found that humpback whales were significantly less likely to interact socially (e.g., joining a group) in the presence of a vessel, whether it was towing an active airgun array or not, at greater ranges and received sound levels lower than the recommended thresholds.

In the northwest Atlantic, sighting rates were significantly greater during non-seismic periods compared with periods when a full array was operating, and humpback whales were more likely to swim away and less likely to swim towards a vessel during seismic vs. non-seismic periods (Moulton and Holst 2010). In contrast, sightings of humpback whales from seismic vessels off the U.K. during 1994–2010 indicated that detection rates were similar during seismic and non-seismic periods, although sample sizes were small (Stone 2015). On their summer feeding grounds in southeast Alaska, there was no clear evidence of avoidance, despite the possibility of subtle effects, at received levels up to 172 re 1 μPa on an approximate rms basis (Malme et al. 1985). It has been suggested that South Atlantic humpback whales wintering off Brazil may be displaced or even strand upon exposure to seismic surveys (Engel et al. 2004), but data from subsequent years indicated that there was no observable direct correlation between strandings and seismic surveys (IWC 2007).

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

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

Bowhead whale calls detected in the presence and absence of airgun sounds have been studied extensively in the Beaufort Sea. Bowheads continue to produce calls of the usual types when exposed to airgun sounds on their summering grounds, although numbers of calls detected are significantly lower in the presence than in the absence of airgun pulses (Blackwell et al. 2013, 2015). Blackwell et al. (2013) reported that calling rates in 2007 declined significantly where received SPLs from airgun sounds were 116–129 dB re 1 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 $CSEL_{10\text{-min}}$ (cumulative SEL over a 10-min period) of ~94 dB re 1 μPa^2 · s, decreased at $CSEL_{10\text{-min}}$ >127 dB re 1 μPa^2 · s, and whales were nearly silent at $CSEL_{10\text{-min}}$ >160 dB re 1 μPa^2 · s. Thus, bowhead whales in the Beaufort Sea apparently decreased their calling rates in response to seismic operations, although movement out of the area could also have contributed to the lower call detection rate (Blackwell et al. 2013, 2015).

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

There was no indication that *western gray whales* exposed to seismic sound were displaced from their overall feeding grounds near Sakhalin Island during seismic programs in 1997 (Würsig et al. 1999) and in 2001 (Johnson et al. 2007; Meier et al. 2007; Yazvenko et al. 2007a). However, there were indications of subtle behavioral effects among whales that remained in the areas exposed to airgun sounds (Würsig et al. 1999; Gailey et al. 2007; Weller et al. 2006a) and localized redistribution of some individuals within the nearshore feeding ground so as to avoid close approaches by the seismic vessel (Weller et al. 2002b, 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 μPa_{rms} (Johnson et al. 2007; Nowacek et al. 2012, 2013b). In contrast, preliminary data collected during a seismic program in 2015 showed some displacement of animals from the feeding area and responses to lower sound levels than expected (Gailey et al. 2017; Sychenko et al. 2017).

Gray whales in 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 systematic studies on sperm whales, and there is an increasing amount of information about responses of various odontocetes to seismic surveys based on monitoring studies. Seismic operators and marine mammal observers on seismic vessels regularly see dolphins and other small toothed whales near operating airgun arrays, but in general there is a tendency for most delphinids to show some avoidance of operating seismic vessels (e.g., Stone and Tasker 2006; Moulton and Holst 2010; Barry et al. 2012; Wole and Myade 2014; Stone 2015; Monaco et al. 2016). In most cases, the avoidance radii for delphinids appear to be small, on the order of 1 km or less, and some individuals show no apparent avoidance.

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

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

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

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

Most studies of *sperm whales* exposed to airgun sounds indicate that the sperm whale shows considerable tolerance of airgun pulses; in most cases the whales do not show strong avoidance (e.g., Stone and Tasker 2006; Moulton and Holst 2010). Winsor et al. (2017) outfitted sperm whales in the Gulf of Mexico with satellite tags to examine their spatial distribution in relation to seismic surveys. They found no evidence of avoidance or changes in orientation by sperm whales to active seismic vessels. Based on data collected by observers on seismic vessels off the U.K. from 1994–2010, detection rates for sperm whales were similar when large arrays of airguns were operating vs. silent; however, during surveys with small arrays, the detection rate was significantly higher when the airguns were not in operation (Stone 2015). Foraging behavior can also be altered upon exposure to airgun sound (e.g., Miller et al. 2009), which according to Farmer et al. (2017), could have significant consequences on individual fitness. Preliminary data from the Gulf of Mexico show a correlation between reduced sperm whale acoustic activity and periods with airgun operations (Sidorovskaia et al. 2014).

There are almost no specific data on the behavioral reactions of *beaked whales* to seismic surveys. Most beaked whales tend to avoid approaching vessels of other types (e.g., Würsig et al. 1998) and/or change their behavior in response to sounds from vessels (e.g., Pirotta et al. 2012). Thus, it is likely that most beaked whales would also show strong avoidance of an approaching seismic vessel. Observations from seismic vessels off the U.K. from 1994–2010 indicated that detection rates of beaked whales were significantly higher ($p<0.05$) when airguns were not operating vs. when a large array was in operation, although sample sizes were small (Stone 2015). Some northern bottlenose whales remained in the general area and continued to produce high-frequency clicks when exposed to sound pulses from distant seismic surveys (e.g., Simard et al. 2005).

The limited available data suggest that *harbor porpoises* show stronger avoidance of seismic operations than do Dall's porpoises. The apparent tendency for greater responsiveness in the harbor porpoise is consistent with its relative responsiveness to boat traffic and some other acoustic sources (Richardson et al. 1995; Southall et al. 2007). Based on data collected by observers on seismic vessels off the U.K. from 1994–2010, detection rates of harbor porpoises were significantly higher when airguns were silent vs. when large or small arrays were operating (Stone 2015). In addition, harbor porpoises were seen farther away from the array when it was operating vs. silent, and were most often seen traveling away from the airgun array when it was in operation (Stone 2015). Thompson et al. (2013) reported decreased densities and reduced acoustic detections of harbor porpoise in response to a seismic survey in Moray Firth, Scotland, at ranges of 5–10 km (SPLs of 165–172 dB re 1 µPa, SELs of 145–151 dB $\mu Pa^2 \cdot s$). For the same survey, Pirotta et al. (2014) reported that the probability of recording a porpoise buzz decreased by 15% in the ensonified area, and that the probability was positively related to the distance from the seismic ship; the decreased buzzing occurrence may indicate reduced foraging efficiency. Nonetheless, animals returned to the area within a few hours (Thompson et al. 2013). Similar avoidance behavior and/or decreases in echolocation signals during 3-D seismic operations were reported for harbor porpoise in the North Sea (Sarnocińska et al. 2020). In a captive facility, harbor porpoise showed avoidance of a pool with elevated sound levels, but search time for prey within that pool was no different than in a quieter pool (Kok et al. 2017).

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

Odontocete reactions to large arrays of airguns are variable and, at least for delphinids, seem to be confined to a smaller radius than has been observed for the more responsive of the mysticetes and some other odontocetes. A ≥170 dB disturbance criterion (rather than ≥160 dB) is considered appropriate for delphinids, which tend to be less responsive than the more responsive cetaceans. NMFS is developing new guidance for predicting behavioral effects (Scholik-Schlomer 2015). As behavioral responses are not consistently associated with received levels, some authors have made recommendations on different approaches to assess behavioral reactions (e.g., Gomez et al. 2016; Harris et al. 2017; Tyack and Thomas 2019).

Pinnipeds

Pinnipeds are not likely to show a strong avoidance reaction to an airgun array. Visual monitoring from seismic vessels has shown only slight (if any) avoidance of airguns by pinnipeds and only slight (if any) changes in behavior. However, telemetry work has suggested that avoidance and other behavioral reactions may be stronger than evident to date from visual studies (Thompson et al. 1998). Observations from seismic vessels operating large arrays off the U.K. from 1994–2010 showed that the detection rate for gray seals was significantly higher when airguns were not operating; for surveys using small arrays, the detection rates were similar during seismic vs. non-seismic operations (Stone 2015). No significant differences in detection rates were apparent for harbor seals during seismic and non-seismic periods (Stone 2015). There were no significant differences in CPA distances of grey 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.

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; Popov et al. 2011, 2013; Finneran 2012, 2015; Ketten 2012; Kastelein et al. 2012a,b; 2013b,c, 2014, 2015a, 2016a,b, 2017, 2018, 2019b,c, 2020a,b,c,d,e; Supin et al. 2016).

Studies have shown that the SEL required for TTS onset to occur increases with intermittent exposures, with some auditory recovery during silent periods between signals (Finneran et al. 2010b; Finneran and Schlundt 2011). Studies on bottlenose dolphins by Finneran et al. (2015) indicate that the potential for seismic surveys using airguns to cause auditory effects on dolphins could be lower than previously thought. Based on behavioral tests, no measurable TTS was detected in three bottlenose dolphins after exposure to 10 impulses from a seismic airgun with a cumulative SEL of up to ~195 dB re 1 µPa2 · s (Finneran et al. 2015; Schlundt et al. 2016). However, auditory evoked potential measurements were more variable; one dolphin showed a small (9 dB) threshold shift at 8 kHz (Finneran et al. 2015; Schlundt et al. 2016).

Studies have also shown that the SEL necessary to elicit TTS can depend substantially on frequency, with susceptibility to TTS increasing with increasing frequency above 3 kHz (Finneran and Schlundt 2010, 2011; Finneran 2012). When beluga whales were exposed to fatiguing noise with sound levels of 165 dB re 1 µPa for durations of 1–30 min at frequencies of 11.2–90 kHz, the highest TTS with the longest recovery time was produced by the lower frequencies (11.2 and 22.5 kHz); TTS effects also gradually increased with prolonged exposure time (Popov et al. 2013). Additionally, Popov et al. (2015) demonstrated that the impacts of TTS include deterioration of signal discrimination. Kastelein et al. (2015b, 2017) reported that exposure to multiple pulses with most energy at low frequencies can lead to TTS at higher frequencies in some cetaceans, such as the harbor porpoise. When a porpoise was exposed to 10 and 20 consecutive shots (mean shot interval ~17 s) from two airguns with a SEL_{cum} of 188 and 191 μPa$^2 \cdot$ 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. 2020f).

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; 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 to 88.4 kHz, Kastelein et al. (2019c,d, 2020d,e) 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. Popov et al. (2011) examined the effects of fatiguing noise on the hearing threshold of Yangtze finless porpoises when exposed to frequencies of 32–128 kHz at 140–160 dB re 1 μPa for 1–30 min. They found that an exposure of higher level and shorter duration produced a higher TTS than an exposure of equal SEL but of lower level and longer duration. Popov et al. (2011) reported a TTS of 25 dB for a Yangtze finless porpoise that was exposed to high levels of 3-min pulses of half-octave band noise centered at 45 kHz with an SEL of 163 dB.

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

Initial evidence from exposures to non-pulses has also suggested that some pinnipeds (harbor seals in particular) incur TTS at somewhat lower received levels than do most small odontocetes exposed for similar durations (Kastak et al. 1999, 2005, 2008; Ketten et al. 2001). Harbor seals appear to be equally susceptible to incurring TTS when exposed to sounds from 2.5 to 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).

A maximum TTS of 44 dB was reported for a harbor seal exposed to an octave-band white noise centered at 4 kHz with a mean received SPL of 163 dB for 1 h; for a harbor seal exposed to 4 kHz for 1 h with mean SPLs of 124–148 dB, the onset of PTS would require a level of at least 22 dB above the TTS onset (Kastelein et al. 2013c). A maximum TTS >45 dB was elicited from a harbor seal exposed to 32 kHz at 191 dB SEL (Kastelein et al. 2020a). 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). However, free-swimming harbor and other 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).

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). When Matthews et al. (2021) modeled the potential of serious injury/mortality using the above PTS thresholds, they found that few marine mammals would be exposed to airgun sounds that could be injurious, although porpoise appeared to be more susceptible to being exposed to injurious sounds.

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 show some avoidance of the area where received levels of airgun sound are high enough such that hearing impairment could potentially occur. In those cases, the avoidance responses of the animals themselves would reduce or (most likely) avoid any possibility of hearing impairment. Aarts et al. (2016) noted that an understanding of animal movement is necessary in order to estimate the impact of anthropogenic sound on cetaceans.

Non-auditory physical effects may also occur in marine mammals exposed to strong underwater pulsed sound. Possible types of non-auditory physiological effects or injuries that might (in theory) occur in mammals close to a strong sound source include stress, neurological effects, bubble formation, and other types of organ or tissue damage. Gray and Van Waerebeek (2011) have suggested a cause-effect relationship between a seismic survey off Liberia in 2009 and the erratic movement, postural instability, and akinesia in a pantropical spotted dolphin based on spatially and temporally close association with the airgun array. It is possible that some marine mammal species (i.e., beaked whales) are especially susceptible to injury and/or stranding when exposed to strong transient sounds (e.g., Southall et al. 2007). Ten cases of cetacean strandings in the general area where a seismic survey was ongoing have led to speculation concerning a possible link between seismic surveys and strandings (Castellote and Llorens 2016). An analysis of stranding data found that the number of long-finned pilot whale strandings along Ireland's coast increased with seismic surveys operating offshore (McGeady et al. 2016). However, there is no definitive evidence that any of these effects occur even for marine mammals in close proximity to large arrays of airguns. Morell et al. (2017) examined the inner ears of long-finned pilot whales after a mass stranding in Scotland and reported damage to the cochlea compatible with over-exposure from underwater noise; however, no seismic surveys were occurring in the vicinity in the days leading up to the stranding. Morell et al. (2020) described new methodology that visualizes scars in the cochlea to detect hearing loss in stranded marine mammals.

Since 1991, there have been 70 Marine Mammal UMEs in the U.S. (NOAA 2021e). 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.

4.1.1.2 Possible Effects of Other Acoustic Sources

The Kongsberg EM 302 MBES, Kongberg TOPAS PS-18 SBP, ADCP, and pingers would be operated from the source vessel during the proposed surveys. Information about these types of sound sources was provided in § 2.2.3.1 of the PEIS. A review of the expected potential effects (or lack thereof) of MBESs, SBPs, ADCP, and pingers on marine mammals appears in § 3.6.4.3, § 3.7.4.3, and § 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 is the first known marine mammal mass stranding closely associated with the operation of an MBES. Leading scientific experts knowledgeable about MBES expressed concerns about the independent scientific review panel analyses and findings (Bernstein 2013).

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

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

There is nearly no available information on marine mammal behavioral responses to MBES sounds (Southall et al. 2013). 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 of Cuvier's beaked whales during multibeam mapping in southern California (Varghese et al. 2020). The study found that the number of GVP per hour increased during as well as after multibeam mapping compared with before MBES exposure, and that the animals neither left the area nor stopped foraging during the MBES surveys. During an analogous study assessing Naval sonar (McCarthy et al. 2011), significantly fewer GVPs were recorded for Blainville's beaked whales 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).

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

Despite the aforementioned information that has become available in the last decade, this Draft EA remains in agreement with the assessment presented in § 3.6.7, 3.7.7, and 3.8.7 of the PEIS that operation of MBESs, SBPs, and pingers is not likely to impact marine mammals (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 given the movement and speed of the vessel.

4.1.1.3 Other Possible Effects of Seismic Surveys

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

Ship noise, through masking, can reduce the effective communication distance of a marine mammal if the frequency of the sound source is close to that used by the animal, and if the sound is present for a significant fraction of time (e.g., Richardson et al. 1995; Clark et al. 2009; Jensen et al. 2009; Gervaise et al. 2012; Hatch et al. 2012; Rice et al. 2014; Dunlop 2015; Erbe et al. 2016; Jones et al. 2017; Putland et al. 2017; Cholewiak et al. 2018; Williams et al. 2020). 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). In order to compensate for increased ambient noise, some cetaceans are known to increase the source levels of their calls in the presence of elevated noise levels from shipping, shift their peak frequencies, or otherwise change their vocal behavior (e.g., Parks et al. 2011, 2012, 2016a,b; Castellote et al. 2012; Melcón et al. 2012; Azzara et al. 2013; Tyack and Janik 2013; Luís et al. 2014; Sairanen 2014; Papale et al. 2015; Bittencourt et al. 2016; Dahlheim and Castellote 2016; Gospić and Picciulin 2016; Gridley et al. 2016; Heiler et al. 2016; Martins et al. 2016; O'Brien et al. 2016; Tenessen and Parks 2016; Fornet et al. 2018; Halliday et al. 2019). Similarly, harbor seals increased the minimum frequency and amplitude of their calls in response to vessel noise (Matthews 2017); however, harp seals did not increase their call frequencies in environments with increased low-frequency sounds (Terhune and Bosker 2016).

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

Baleen whales are thought to be more sensitive to sound at these low frequencies than are toothed whales (e.g., MacGillivray et al. 2014), possibly causing localized avoidance of the proposed survey areas during seismic operations. Reactions of gray and humpback whales to vessels have been studied, and there is limited information available about the reactions of right whales and rorquals (fin, blue, and minke whales). Reactions of humpback whales to boats are variable, ranging from approach to avoidance (Payne 1978; Salden 1993). Baker et al. (1982, 1983) and Baker and Herman (1989) found humpbacks often move away when vessels are within several kilometers. Humpbacks seem less likely to react overtly when actively feeding than when resting or engaged in other activities (Krieger and Wing 1984, 1986). Increased levels of ship noise have been shown to affect foraging by humpback whales (Blair et al. 2016). 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). Noise and/or physical presence of vessels has been shown to disturb the foraging activity of bottlenose dolphins (Pirotta et al. 2015), blue whales (Lesage et al. 2017) and killer whales (Holt et al. 2020). 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.

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, 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 (e.g., Redfern et al. 2013). Information on vessel strikes is reviewed in § 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 exists but is extremely unlikely, because of the relatively slow operating speed (typically 7–9 km/h) of the vessel during seismic operations, and the generally straight-line movement of the seismic vessel. There has been no history of marine mammal vessel strikes with R/V *Sikuliaq* or other NSF-owned vessels over the last two decades.

4.1.1.4 Mitigation Measures

Several mitigation measures are built into the proposed seismic surveys as an integral part of the planned activity. These measures include the following: ramp ups; typically two, however a minimum of one dedicated observer maintaining a visual watch during all daytime airgun operations; two observers for 30 min before and during ramp ups; PAM during the day and night to complement visual monitoring (unless the system and back-up systems are damaged during operations); and shut downs when marine mammals are detected in or about to enter the designated EZ. These mitigation measures are described in § 2.4.4.1 of the PEIS and summarized earlier in this document, in § II (2.1.3). The fact that the airgun array, because of its design, would direct the majority of the energy downward, and less energy laterally, is also an inherent mitigation measure. 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 Marine Mammals Exposed to Received Sound Levels ≥160 dB

All takes would be anticipated to be Level B "takes by harassment" as described in § I, involving temporary changes in behavior. Consistent with past similar proposed actions, NSF has followed the NOAA *Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing* for estimating Level A takes. Although NMFS may issue Level A takes for the remote possibility of low-level physiological effects, because of the characteristics of the proposed activities and the proposed monitoring and mitigation measures, in addition to the general avoidance by marine mammals of loud sounds, injurious takes would not be expected. (However, as noted earlier and in the PEIS, there is no specific information demonstrating that injurious Level A "takes" would occur even in the absence of the planned mitigation measures.) In the sections below, we describe methods to estimate the number of potential exposures to Level A and Level B sound levels and present estimates of the numbers of marine mammals that could be affected during the proposed seismic surveys. The estimates are based on consideration of the number of marine mammals that could be harassed by sound (Level B takes) produced by the seismic surveys in the Arctic Ocean.

The Level B estimates are based on a consideration of the number of marine mammals that could be within the area around the operating airgun array where received levels of sound ≥160 dB re 1 μPa_{rms} are predicted to occur (see Table 1). It should be noted that 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 2016c). It has become evident that the context of an exposure of a marine mammal to sound can affect the animal's initial response to the sound (NMFS 2016c).

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

Habitat-based estimates of cetacean density in the U.S. Arctic were published by Schick et al. (2017). This study used line-transect aerial survey data from ASAMM collected in the U.S. Chukchi and Beaufort seas from 2000–2016 and associated habitat covariates to estimate abundance monthly (from July through October) within 10 km x 10 km grid cells (equivalent to a density in units of individuals/100 km^2) which are provided in GIS raster files. Estimates were produced for bowhead, gray, and beluga whales, as well as a guild of other "baleen whales" that included fin, humpback, and minke whales. However, the spatial extent of the density estimates differed by species and therefore proximity to the survey area. For all species except beluga whales, the methods described below that were used to extend the Schick et al. (2017) predictions to areas farther north likely produced conservative density estimates since those species are rarely sighted in the survey area.

The spatial coverage of density estimates for bowhead whales extends northward to ~74°N, which overlaps the southern-most survey lines by ~25 km. However, the majority of the survey lines do not overlap with the spatial coverage of the Schick et al. (2017) density estimates, so the following method was used to produce a conservative estimate of average bowhead density farther north. The two northern-most rows of 10 km x 10 km grid cells (i.e., northern 20 km of estimates) and the two additional cells overlapped by the southern-most survey lines, were selected from the bowhead whale GIS raster files for August and September between 140°W and 165°W, the approximate east-west extend of the survey lines. Density estimates within those cells were then evaluated and cells east of ~157°W were excluded as they contained densities that were effectively zero which would reduce the calculated average. The mean of the remaining cells (west of 157°W) was then calculated resulting in an overall density estimate of 0.01237 whales/km^2 (Table 7).

The same process was used to calculate densities for gray whales and the baleen whale guild, except that the northern extent of the spatial coverage from Schick et al. (2017) for those species is ~73°N. This meant there was no overlap with any of the survey lines and no additional cells beyond the two northern-most rows (20 km) were used in the calculations. The resulting density estimates were extremely small, 0.0000001 and 0.00002 individuals/1000 km^2 for gray whales and other baleen whales, respectively. These are shown as zero in Table 7.

For beluga whales, the spatial coverage of the Schick et al. (2017) density estimates overlapped the full extent of survey lines and associated ensonified areas. To calculate an average beluga whale density in areas that may be exposed above threshold levels, we selected all grid cells from the August and September estimates that overlapped (wholly or partially) with the 160-dB ensonifed area and calculated the mean, resulting in an estimate of 0.0255 whales/km^2 (Table 7).

During ASAMM, sightings of pinnipeds were recorded when possible and the resulting data were used by Schick et al. (2017) to produce habitat-based density estimates in the same manner as for cetaceans. However, given ASAMM was designed for large whales, including typically being flown at altitudes above 1000 ft above sea level, and small pinniped sightings may not have been recorded as consistently, the

TABLE 7. Densities, calculated exposures, and requested number of takes of marine mammals that could be exposed to airgun sounds during the proposed survey in the Arctic Ocean during summer 2021. Species in italics are listed under the ESA as threatened or endangered.

Species	Density (Individuals/km^2)	Ensonified Area (km^2) Level B	Ensonified Area (km^2) Level A	Calculated Takes Level B	Calculated Takes Level A	Requested Take Authorization[1]	Regional Population Size	Take by % of Pop.
LF Cetaceans								
Bowhead whale	*0.0124*	*27,309*	*279*	*334*	*3*	*337*	*16,820*	*2.00*
Gray whale^	0	27,309	279	0	0	**2**	26,960	0.01
Humpback whale^	0	27,309	279	0	0	**2**	11,210	0.02
Fin whale	*0*	*27,309*	*279*	*0*	*0*	**2**	*13,620*	*0.01*
Minke whale	0	27,309	279	0	0	**2**	20,000	0.01
MF Cetaceans								
Beluga whale	0.0255	27,309	45	696	1	697	60,010	1.16
Killer whale	-	27,309	45	-	-	**6**	2,934	0.20
Narwhal	-	27,309	45	-	-	2*	-	-
HF Cetaceans								
Harbor porpoise	-	27,309	1175	-	-	**2**	48,215	<0.01
Phocid Seals								
Bearded seal	*0.0332*	*27,309*	*187*	*900*	*6*	*907*	*125,000*	*0.73*
Ribbon seal	0.0677	27,309	187	1,836	13	1,849	184,697	1.00
Ringed seal	*0.3760*	*27,309*	*187*	*10,198*	*70*	*10,269*	*171,418*	*5.99*
Spotted seal	0.0007	27,309	187	19	0	19	461,625	<0.01
Other Pinnipeds								
Walrus	15 individuals/day	-	-	-	-	158	129,000	0.12
Marine Fissipeds								
Polar bear	*0.5 individuals/day*	-	-	-	-	*15*	*2,937*	*0.51*

1 Numbers in bold based on group sizes from ASAMM. * Arbitrary estimate based on extralimital sightings. ^ No takes for ESA-listed DPS expected.

Schick et al. (2017) pinniped densities were not used in this analysis. As an alternative, NMFS recommended using bearded and ringed seal densities from their Biological Opinion for the Navy's Arctic Research Activities 2018–2021 (NMFS 2019b), which were based on habitat-based modeling by Kaschner et al. (2006) and Kaschner (2004) (see Table 7).

Spotted and ribbon seals were not included in NMFS (2019b). Thus, spotted seal densities were estimated by multiplying ringed seal density by 0.18. This was based on the ratio of the estimated Chukchi Sea populations of the two species (Table 7). The Alaskan population of spotted seals is 461,625 (Muto et al. 2020), and ~8% of the population (~37,000) is estimated to be present in the Chukchi Sea during the summer and fall (Rugh et al. 1997). As the population of ringed seals in the Alaskan Chukchi Sea is ~208,000 animals (Bengtson et al. 2005), this resulted in a ratio of 0.18. Based on Hartin et al. (2013), four ribbon seal sightings were reported during industry vessel operations in the Chukchi Sea from 2006 through 2010, resulting in a density estimate of 0.0007/km^2 (Table 7).

Although Schick et al. (2017) included estimates of walrus density with the same spatial coverage as gray whales and the other baleen whale guild, this density (0.000008 walrus/km^2) was not deemed to be the best available data to estimate walrus take, as sightings were available from two surveys in the region that encountered walrus near or within the southern half of the proposed survey area. RPS (2012) reported four sightings totaling nine walrus (mean group size of 2.3) during ~24 days of activities north of 70°N or ~0.4 walrus/day. In 2018, R/V *Sikuliaq* conducted ~8 days of activities and recorded seven sightings of 84 walrus (mean group size of 12) or ~10.5 walrus per day, all north of 72°N but south of 73.5°N (U.S.

Navy 2019a). To account for potential encounters of walrus in the southern half of the proposed survey area, the highest encounter rate (~10.5 walrus/day) was multiplied by 15 days of seismic survey activity (half of the total planned ~30 days).

As described in Section 3.3.4, polar bears have been encountered by vessels conducting activities in and near the survey area in the past. Haley and Ireland (2006) reported an overall sighting rate of 4.5 polar bears/1000 km of vessel transit within leads or polynyas and while icebreaking, while Beland and Ireland (2010) reported a sighting rate of 4.3 sightings/1000 km when icebreaking and a lower rate of 2.9 sightings/1000 km when not icebreaking. The sightings reported by Beland and Ireland (2010) occurred over the course of ~32 days of activities in the region, resulting in an encounter rate of 0.44 polar bears/day; the sightings in Haley and Ireland (2006) occurred over ~48 days, resulting in an encounter rate of 0.5 polar bears/day. RPS (2012) reported no polar bear sightings in open water between 72° and 77°N during ~23 days of survey activity in 2011. Lastly, U.S. Navy (2019a) reported polar bear sightings from activities by R/V *Sikuliaq* and U.S. Coast Guard Cutter (USCGC) *Healy* in 2018 and 2019, with daily sighting rates from 0.17 to 0.5 polar bears/day, and a mean group size of 2. The highest sighting rate per day (0.5 individuals/day) was used as an estimated encounter rate during the planned survey involving ~30 days of seismic surveys. This is likely a high estimate since most of the polar bears observed during these prior activities were on ice, and R/V *Sikuliaq* plans to remain distant from ice during this survey.

Although walrus and polar bears are unlikely to be encountered, given that R/V *Sikuliaq* would avoid ice, we have included preliminary high estimates for walrus and polar bear takes in Table 7 that may be revised later depending in consultation with USFWS. Given that R/V *Sikuliaq* plans to avoid ice, more realistic take estimates are likely to equal the mean group size for walrus (12) and polar bear (2).

Highly variable oceanographic and atmospheric conditions determine the amount and distribution of sea ice in the Arctic, which heavily influences the species and number of marine mammals potentially present at these high latitudes. Thus, there is considerable year-to-year variation in the distribution and abundance of the marine mammal species in the survey area. Thus, for some species, the densities derived from past surveys may not be representative of the densities that would be encountered during the proposed seismic surveys. However, the approach used here is based on the best available data.

The number of individual marine mammals potentially exposed to airgun sounds with received levels ≥160 dB re 1 μPa_{rms} (Level B) was calculated by multiplying the estimated densities by the total area expected to be ensonified above the Level B threshold; these are shown as *Requested Take Authorization*. The 160-dB re 1 μPa_{rms} criterion assumes that marine mammals exposed to airgun sounds that strong could change their behavior sufficiently to be considered "taken by harassment". The area expected to be ensonified was determined by entering the planned survey lines into a GIS and then "buffering" the lines by the applicable 160-dB distance (see Appendix B). The resulting ensonified areas were then increased by 25% to allow for any necessary additional operations, such as re-surveying segments where data quality was insufficient. This approach assumes that no marine mammals would move away or toward the trackline in response to increasing sound levels before the levels reach the threshold as R/V *Sikuliaq* approaches.

For most species for which no densities were available or the calculations resulted in zero estimated exposures, we included a *Requested Take Authorization* based on average group size from ASAMM; average group size was determined from sightings made during surveys in 2016–2019 (Clarke e al. 2017, 2018, 2019, 2020).

Table 7 shows the calculated number of marine mammals that could potentially be exposed to ≥160 dB re 1 μPa_{rms} during the proposed seismic surveys if no animals moved away from the survey vessel. Since the estimates of the numbers of marine mammals potentially exposed to sounds ≥160 dB re 1 μPa_{rms}

include several conservative assumptions, they likely overestimate the actual numbers of marine mammals that could be affected.

Estimates of the numbers of marine mammals that could be exposed to seismic sounds 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 7. 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. However, 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

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".

In § 3.6.7, § 3.7.7, and § 3.8.7 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, 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 2019c,d).

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 7). The proposed activities are likely to adversely affect ESA-listed species for which takes have been requested (Table 8). 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 NSF-owned vessels, PSOs and other crew members have seen no seismic sound-related marine mammal injuries or mortality. Similar surveys conducted in the region in the past had no observed significant impacts. 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, ~5500-km, 2-D seismic survey conducted by R/V *Langseth* in the Arctic Ocean in September–October 2011, only 11 pinnipeds were observed within the predicted 160-dB zone and potentially taken, representing ~0.1% of the 9,323 takes authorized by NMFS (RPS 2012). 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.

TABLE 8. ESA determination for marine mammal species that could be encountered during the proposed surveys in the Arctic Ocean during summer 2021.

Species	ESA Determination		
	No Effect	May Affect – Not Likely to Adversely Affect	May Affect – Likely to Adversely Affect
North Pacific Right Whale	√		
Bowhead Whale			√
Gray Whale (Western Pacific DPS)		√	
Humpback Whale (Western Pacific DPS)		√	
Humpback Whale (Mexico DPS)		√	
Fin Whale			√
Sei Whale	√		
Blue Whale	√		
Arctic Ringed Seal			√
Pacific Bearded Seal (Beringia DPS)			√
Polar Bear			√

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

Effects of seismic sound on marine invertebrates (crustaceans and cephalopods), marine fish, and their fisheries are discussed in § 3.2.4 and § 3.3.4 and Appendix D of the PEIS. Relevant new studies on the effects of sound on marine invertebrates, fish, and fisheries that have been published since the release of the PEIS are summarized below. Although research on the effects of exposure to airgun and other anthropogenic sound on marine invertebrates and fishes is increasing, many data gaps remain (Hawkins et al. 2015, 2020; Carroll et al. 2017; Popper et al. 2020a), 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). 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.

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). In water >250 m deep, the impact of seismic surveying on fish and marine invertebrates was assessed as acceptable, while in water <250 m deep, risk ranged from negligible to severe, depending on depth, resource-type, and sound intensity (Webster et al. 2018). Immobile organisms, such as molluscs, were deemed to be the invertebrates most at risk from seismic impacts.

4.1.2.1 Effects of Sound on Marine Invertebrates

Effects of anthropogenic sounds on marine invertebrates are varied, ranging from no overt reactions to behavioral/physiological responses, injuries, or mortalities (Aguilar de Soto 2016; Edmonds et al. 2016; Carroll et al. 2017; Weilgart 2017b; Elliott et al. 2019). The available information suggests that invertebrates, particularly crustaceans, may be relatively resilient to airgun sounds (Day et al. 2016a,b).

Fields et al. (2019) conducted laboratory experiments to study effects of exposure to airgun sound on the mortality, predator escape response, and gene expression of the copepod *Calanus finmarchicus* and concluded that the airgun sound had limited effects on the mortality and escape responses of copepods exposed within 10 m of the airgun source but no measurable impact beyond that distance. McCauley et al. (2017) conducted a 2-day study to examine the potential effects of sound exposure of a 150 in^3 airgun on zooplankton off the coast of Tasmania; they concluded that exposure to airgun sound decreased zooplankton abundance compared to control samples and caused a two- to three-fold increase in adult and larval zooplankton mortality. They observed impacts on the zooplankton as far as 1.2 km from the exposure location – a much greater impact range than previously thought; however, there was no consistent decline in the proportion of dead zooplankton as distance increased and received levels decreased. The conclusions by McCauley et al. (2017) were based on a relatively small number of zooplankton samples, and more replication is required to increase confidence in the study findings.

Richardson et al. (2017) presented results of a modeling exercise intended to investigate the impact of exposure to airgun sound on zooplankton over a much larger temporal and spatial scale than that employed by McCauley et al. (2017). The exercise modeled a hypothetical survey over an area 80 km by 36 km during a 35-day period. Richardson et al. (2017) postulated that the decrease in zooplankton abundance observed by McCauley et al. (2017) could have been due to active avoidance behavior by larger zooplankton. The modeling results did indicate that there would be substantial impact on the zooplankton populations at a local spatial scale but not at a large spatial scale; zooplankton biomass recovery within the exposure area and out to 15 km occurred 3 days after completion of the seismic survey.

Fewtrell and McCauley (2012) exposed captive squid (*Sepioteuthis australis*) to pulses from a single airgun; the received sound levels ranged from 120–184 dB re 1 dB re 1 $\mu Pa^2 \cdot s$ SEL. Increases in alarm responses were seen at SELs >147–151 dB re 1 $\mu Pa^2 \cdot s$; the squid were seen to discharge ink or change their swimming pattern or vertical position in the water column. Solé et al. (2013a,b) exposed four cephalopod species held in tanks to low-frequency (50–400 Hz) sinusoidal wave sweeps (with a 1-s sweep period for 2 h) with received levels of 157 ± 5 dB re 1 µPa and peak levels up to 175 dB re 1 µPa. Besides exhibiting startle responses, all four species examined received damage to the statocyst, which is the organ responsible for equilibrium and movement. The animals also showed stressed behavior, decreased activity, and loss of muscle tone (Solé et al. 2013a). To examine the contribution from near-field particle motion from the tank walls on the study, Solé et al. (2017) exposed common cuttlefish (*Sepia officinalis*) in cages in their natural habitat to 1/3 octave bands with frequencies centered at 315 Hz and 400 Hz and levels ranging from 139–141 re 1 μPa^2. The study animals still incurred acoustic trauma and injury to statocysts, despite not being held in confined tanks with walls.

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

There have been several *in situ* studies that have examined the effects of seismic surveys on scallops. Although most of these studies showed no short-term mortality in scallops (Parry et al. 2002; Harrington et al. 2010; Przeslawski et al. 2016, 2018), one study (Day et al. 2016a,b, 2017) did show adverse effects including an increase in mortality rates. Przeslawski et al. (2016, 2018) studied the potential impacts of an industrial seismic survey on commercial (*Pecten fumatus*) and doughboy (*Mimachlamys asperrima*) scallops. *In situ* monitoring of scallops took place in the Gippsland Basin, Australia, using dredging, and autonomous underwater vehicle deployment before the seismic survey, as well as two, and ten months after the survey. The airgun array used in the study was a single 2530 in^3 array made up of 16 airguns operating at 2000 psi with a maximum SEL of 146 dB re 1 $\mu Pa^2 \cdot s$ 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 lobsters (*Jasus edwardsi*) at a location 10–12 m below the surface to airgun sounds. The airgun source was started ~1–1.5 km from the study subjects and passed over the animals; thus, the scallops and lobsters were exposed to airgun sounds as close as 5–8 m away and up to 1.5 km from the source. Three different airgun configurations were used in the field: 45 in^3, 150 in^3 (low pressure), and 150 in^3 (high pressure), each with maximum peak-to-peak source levels of 191–213 dB re 1 µPa; maximum cumulative SEL source levels were 189–199 dB re 1 $µPa^2 \cdot s$. Exposure to seismic sound was found to significantly increase mortality in the scallops, especially over a chronic time scale (i.e., months post-exposure), although not beyond naturally occurring rates of mortality (Day et al. 2017). Non-lethal effects were also recorded, including changes in reflex behavior time, other behavioral patterns, haemolymph chemistry, and apparent damage to statocysts (Day et al. 2016b, 2017). However, the scallops were reared in suspended lantern nets rather than their natural environment, which can result in higher mortality rates compared to benthic populations (Yu et al. 2010). The female lobsters were maintained until the eggs hatched; no significant differences were found in the quality or quantity of larvae for control versus exposed subjects, indicating that the embryonic development of spiny lobster was not adversely affected by airgun sounds (Day et al. 2016a,b). No mortalities were reported for either control or exposed lobsters (Day et al. 2016a,b). When Day et al. (2019) exposed rock lobster to the equivalent of a full-scale commercial seismic survey passing within 100–500 m, lobsters exhibited impaired righting and damage to the sensory hairs of the statocyst. However, lobsters with pre-existing damage to the statocyst were not damaged further by being exposed to airgun sounds, and appeared to cope or adapt to the damage (Day et al. 2020).

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

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

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 μPa_{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. Hall et al. (2021) also found some stress response in snow crabs that were exposed to seismic survey sounds. BACI experiments on shore crab movements before and during seismic surveys showed subtle, if any, changes in behavior from exposure to airgun sounds (Cote et al. 2020). 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. Roberts and Laidre (2019) found that an impulsive sound source (underwater slide hammer) can act cross-modally to affect chemically-mediated shell searching behaviour of the hermit crab (*Pagarus acadianus*); exposures consisted of repetitive low-frequency pulses, with most energy within the 500–700 Hz range.

Leite et al. (2016) reported observing a dead giant squid (*Architeuthis dux*) while undertaking marine mammal observation work aboard a seismic vessel conducting a seismic survey in offshore Brazil. The seismic vessel was operating 48-airgun array with a total volume of 5085 in^3. As no further information on the squid could be obtained, it is unknown whether the airgun sounds played a factor in the death of the squid.

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

4.1.2.2 Effects of Sound on Fish

Popper et al. (2019a, 2020b) recently reviewed the hearing ability of fishes, and Ladich (2019) presented information on the ecology of sound communication in fish. Potential impacts of exposure to airgun sound on marine fishes have been reviewed by such authors as Popper (2009), Popper and Hastings (2009a,b), Fay and Popper (2012), Carroll et al. (2017), Weilgart (2017b), Hawkins and Popper (2018), Popper and Hawkins (2019), Popper et al. (2019b), and Slabbekoorn et al. (2019); they include pathological, physiological, and behavioral effects. Masking of key environmental sounds or social signals could also be a potential negative effect from sound (Radford et al. 2014; Putland et al. 2017; Pine et al. 2020). Popper et al. (2014) presented guidelines for seismic sound level thresholds related to potential effects on fish. The effect types discussed include mortality, mortal injury, recoverable injury, temporary threshold shift, masking, and behavioral effects. Seismic sound level thresholds were discussed in relation to fish without swim bladders, fish with swim bladders, and fish eggs and larvae. Hawkins and Popper (2017) cautioned that particle motion as well as sound pressure should be considered when assessing the effects of underwater sound on fishes.

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 $\mu Pa^2 \cdot s$).

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

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

Davidsen et al. (2019) outfitted Atlantic cod and saithe with acoustic transmitters to monitor their behaviors (i.e., swimming speed, movement in water column) in response to exposure to seismic airgun sound. The study was conducted in Norway using a large sea cage with a 30 m diameter and 25 m depth. Both sound pressure and particle motion were measured within the sea cage. An airgun firing every 10 s was towed toward the sea cage from an initial distance of 6.7 km from the cage to a minimum distance of 100 m from the cage. The SEL_{cum} ranged from 172–175 dB re 1 $\mu Pa^2 \cdot s$. Both the cod and saithe changed swimming depth and horizontal position more frequently during exposure to the sound. The saithe became more dispersed in response to elevated sound levels. Both species exhibited behavioral habituation to the repeated exposures to sound. Similarly, Hubert et al. (2020) found that Atlantic cod exposed to playback sounds of airguns changed the amount of time spent in various behavioral states.

Radford et al. (2016) conducted experiments examining how repeated exposures of different sounds to European seabass (*Dicentrarchus labrax*) can reduce the fishes' response to that sound. They exposed post-larval seabass to playback recordings of seismic survey sound (single strike SEL 144 dB re 1 $\mu Pa^2 \cdot s$) in large indoor tanks containing underwater speakers. Their findings indicated that short-term exposure of seismic sound increased the ventilation rate (i.e., opercular beat rate [OBR]) of seabass that were not previously exposed to seismic relative to seabass in controlled, ambient sound conditions. Fish that were reared in tanks that were repeatedly exposed to seismic sound over a 12-week period exhibited a reduced

OBR response to that sound type, but fish exposed over the same time period to pile-driving noise displayed a reduced response to both seismic and pile-driving noise. An increased ventilation rate is indicative of greater stress in seabass; however, there was no evidence of mortality or effects on growth of the seabass throughout the 12-week study period.

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

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

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

4.1.2.3 Effects of Sound on Fisheries

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

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

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

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

Bruce et al. (2018) studied the potential impacts of an industrial seismic survey in the Gippsland Basin, Australia, on catches in the Danish seine and gillnet fishing sectors for 15 fish species. Catch data were examined from three years before the seismic survey to six months after completion of the survey in an area 13,000 km^2. Overall, there was little evidence of consistent adverse impacts of the seismic survey on catch rates. Six of the 15 species were found to have increased catch rates.

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

Morris et al. (2018) conducted a two-year (2015–2016) BACI study examining the effects of 2-D seismic exploration on catch rates of snow crab (*Chionoecetes opilio*) along the eastern continental slope (Lilly Canyon and Carson Canyon) of the Grand Banks of Newfoundland, Canada. The airgun array used was operated from a commercial seismic exploration vessel; it had a total volume of 4880 in^3, horizontal zero-to-peak SPL of 251 dB re 1 µPa, and SEL of 229 dB re 1 µPa^2·s. The closest approach of the survey vessel to the treatment site in 2015 (year 1 of the study) was 1465 m during 5 days of seismic operations; in 2016 (year 2), the vessel passed within 100 m of the treatment site but the exposure lasted only 2 h. Overall, the findings indicated that the sound from the commercial seismic survey did not significantly reduce snow crab catch rates during days or weeks following exposure. Another BACI study done to examine the effects of a 3-D survey on snow crab catch rates were more inconclusive (Morris et al. 2020). Morris et al. (2018, 2020) attributed the natural temporal and spatial variations in the marine environment as a greater influence on observed differences in catch rates between control and experimental sites than exposure to seismic survey sounds.

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

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

Very few interactions, if any, between the proposed surveys and fishing operations are expected to occur in the offshore survey area. Two possible conflicts in general are R/V *Sikuliaq*'s streamer entangling with fishing gear and the temporary displacement of fishers from the survey area. However, commercial fishing is not permitted within the U.S. Arctic FMP, and subsistence fishing is likely to occur closer to shore. Any fishing vessels would need to keep a safe distance from R/V *Sikuliaq* and the towed seismic equipment. Conflicts would be avoided through communication with the fishing community during the surveys. PSOs would also watch for any impacts the acoustic sources may have on fish during the survey.

Given the proposed activities in the Arctic Ocean, and that ESA-listed fish presence is unlikely in the proposed survey area, no effect is anticipated on ESA-listed fish species (Table 9). In general, impacts from the proposed activities would not be anticipated to be significant or likely to adversely affect marine invertebrates or marine fish, and their fisheries, including commercial, recreational, and subsistence fisheries. In decades of seismic surveys carried out R/V *Sikuliaq* and other NSF-owned vessels, PSOs and other crew members have not observed any seismic sound-related fish or invertebrate injuries or mortality. During similar surveys conducted in the region in the past, there were no observed significant impacts. In addition, given the short-term nature of the study and minimal bottom disturbance anticipated, no adverse effects on Arctic cod EFH are expected within the survey area. HAPC is not present within the survey area; therefore, no adverse impacts would be anticipated on HAPC.

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); the peak hearing sensitivity was found to be between 1500 and 3000 Hz. The best sensitivity of underwater hearing for great cormorants was found to be at 2 kHz, with a hearing threshold of 71 dB re 1 μPa_{rms} (Hansen et al. 2017). Great cormorants were also found to respond to underwater sounds and may have special adaptations for hearing underwater (Johansen et al. 2016; Hansen et al. 2017, 2020; Sørensen 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. ESA-listed seabirds are not anticipated to occur in the proposed survey area, but some individuals could be encountered during transit to and from the survey area. However, the vessel has a very slow operational speed, relatively slow transit speed, downward directed deck lighting, and uses window curtains/shades at night. As USFWS has noted the potential for collisions of seabirds with the vessel as it is traveling along the transit route, the proposed transit may affect but is not likely to adversely affect, ESA-listed seabirds in Alaska (Table 10). In decades of seismic surveys carried out by NSF-owned vessels, PSOs and other crew members have documented no seismic sound-related seabird injuries or mortality and no ESA-listed seabird collisions.

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

The proposed seismic operations would not result in any permanent impact on habitats used by marine mammals, seabirds, or fish or to the food sources they use. The main impact issue associated with the proposed activity would be temporarily elevated 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

TABLE 9. ESA determination for fish species that could occur in the proposed survey area in the Arctic Ocean during summer 2021.

Species	ESA Determination		
	No Effect	May Affect – Not Likely to Adversely Affect	May Affect – Likely to Adversely Affect
Chinook Salmon (Various ESUs)	√		
Chum Salmon (Various ESUs)	√		
Coho Salmon (Various ESUs)	√		
Sockeye Salmon (Various ESUs)	√		

TABLE 10. ESA determination for seabird species.

Species	ESA Determination [1]		
	No Effect	May Affect – Not Likely to Adversely Affect	May Affect – Likely to Adversely Affect
Short-tailed Albatross		√	
Spectacled Eider		√	
Steller's Eider		√	

[1] There would be no effect on ESA-listed seabird species during the proposed seismic survey; however, USFWS has noted the possibility of collisions with R/V *Sikuliaq* during transit to and from the survey area.

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 surveys would have little impact on the abilities of marine mammals to feed in the area where seismic work is planned. No significant indirect impacts on marine mammals, seabirds, or fish would be expected.

4.1.5 Direct Effects on Cultural Resources and Their Significance

The coast and nearshore waters of Alaska are of cultural importance to indigenous peoples for fishing, hunting, gathering, and ceremonial purposes. As noted above in Section 4.1.2.4, impacts from the Proposed Action, however, would not be anticipated to be significant or likely to adversely affect marine invertebrates, marine fish, and their fisheries, including subsistence fisheries.

Marine mammals are legally hunted in Alaskan waters by coastal Alaska Natives. There are seven communities in the North Slope Borough region of Alaska (northwestern and northern Alaska) that harvest seals, including from west to east Point Hope, Point Lay, Wainwright, Utqiaġvik, Atqusak, Nuiqsut, and Kaktovik (Ice Seal Committee 2019). Bearded seals are the preferred species to harvest as food and for skin boat coverings, but ringed seals are also commonly taken for food and their blubber (Ice Seal Committee 2019). Ringed seals are typically harvested during the summer and can extend up to 64 km from shore (Stephen R. Braund & Associates 2010). No ribbon seals have been harvested in any of the North Slope Borough communities since the 1960s (Ice Seal Committee 2019). Table 11 shows number of ice seals harvested in North Slope Borough during the most recent year that data were available. However, number of seals harvested each year varies considerably. The five-year mean annual harvest of Pacific walrus for 2006–2010 was 4852 individuals, with 1782 of those harvested in the U.S. (Muto et al. 2020). The average annual Alaska polar bear harvest for the Southern Beaufort Sea was 33 bears for 2003–2007; the combined annual harvest for Alaska and Canada was 53.6 animals (USFWS 2020a). For the same years, the annual harvest for the Chukchi/Bering Sea stock in Alaska was 37 (USFWS 2020b).

TABLE 11. Seal harvests in 2014 in the North Slope Borough (Ice Seal Committee 2019).

Community	Year	# of Bearded Seals	# of Ringed Seals	# of Spotted Seals
Kaktovik	2014	3	1	0
Nuiqsut	2014	26	58	7
Utqiaġvik	2014	1070	428	98
Atqasuk	1998	3	0	0
Wainwright	2003	79	27	3
Point Lay	2012	55	51	8
Point Hope	2014	183	246	5

A subsistence harvest of bowheads and belugas is also practiced by Alaskan Natives, providing nutritional and cultural needs. In 2019, 36 bowhead whales were taken during the Alaskan subsistence hunt (Suydam et al. 2020). Whaling near Utqiaġvik occurs during spring (April and May) and autumn, and can continue into November, depending on the quota and conditions. Communities that harvested bowheads during 2019 include Utqiaġvik, Gamgell, Kaktovik, Nuiqsut, Point Hope, Point Lay, and Wainwright. Bowhead whales and gray whales are also taken in the aboriginal subsistence hunt in the Russian Federation (Zharikov et al. 2020). During 2019, 135 gray whales and one bowhead whale were harvested at Chukotka.

Beluga whales from the eastern Chukchi Sea stock are an important subsistence resource for residents of the village of Point Lay, adjacent to Kasegaluk Lagoon, and other villages in northwest Alaska. Each year, hunters from Point Lay drive belugas into the lagoon to a traditional hunting location. The belugas have been predictably sighted near the lagoon from late June through mid- to late July (Suydam et al. 2001). The mean annual number of Beaufort Sea belugas landed by Alaska Native subsistence hunters in 2011–2015 was 47, and an average of 92 were taken in Canadian waters (Muto et al. 2020). The mean annual number of Eastern Chukchi Sea belugas landed by Alaska Native subsistence hunters in 2011–2015 was 67 (Muto et al. 2020).

Interactions between the proposed surveys and fishing/hunting operations in the study area are expected to be limited. Although fishing/hunting would not be precluded in the survey area, a safe distance would need to be kept from R/V *Sikuliaq* and the towed seismic equipment. Conflicts would be avoided through direct communication with subsistence fishers/hunters during the surveys. Considering the limited time that the planned seismic surveys would take place and the far offshore location of the surveys, the proposed project is not expected to have any significant impacts to the availability of the subsistence harvest. Therefore, no adverse impacts to cultural resources are anticipated.

4.1.6 Cumulative Effects

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

According to Nowacek et al. (2015), cumulative impacts have a high potential of disturbing marine mammals. Wright and Kyhn (2014) proposed practical management steps to limit cumulative impacts, including minimizing exposure by reducing exposure rates and levels. The results of the cumulative impacts analysis in the PEIS indicated that there would not be any significant cumulative effects to marine resources from the proposed NSF-funded marine seismic research, including the combined use of airguns with MBES, SBP, and acoustic pingers. However, the PEIS also stated that, "A more detailed, cruise-specific cumulative effects analysis would be conducted at the time of the preparation of the cruise-specific EAs, allowing for the identification of other potential activities in the areas of the proposed seismic surveys that may result in cumulative impacts to environmental resources." Here we focus on activities (e.g., research and naval activities, vessel traffic, fisheries interactions) that could impact animals specifically in the proposed survey area; subsistence was discussed in § 4.1.5 above, and would also play a factor in cumulative effects. However, the combination of the proposed surveys with the existing operations in the region would be expected to produce only a negligible increase in overall disturbance effects on marine mammals.

4.1.6.1 Past and Future Research Activities

The University of Alaska conducted seismic surveys in the Arctic Ocean along the edge of the Northwind Ridge in 2005 from USCGC *Healy*. In 2006, the University of Texas undertook seismic surveys in the region from the USCGC *Healy*. During 2011, the University of Alaska collected seismic data in the area from R/V *Langseth*. Additional geophysical data were collected during Extended Continental Shelf surveys conducted from the Canadian Icebreaker *Louis St. Laurent* during 2007–2014. In addition, numerous industry seismic surveys have occurred in the Chukchi and Beaufort seas in the last two decades. As noted earlier, a future IODP project is also likely to occur in the region.

4.1.6.2 Navy Activities

The U.S. Navy currently conducts research activities in the Pacific sector of the Arctic Ocean, including within the proposed survey area. The activities involve the use of active acoustic source deployments, including the deployment of a very low frequency (VLF) source (NMFS 2019b). The scientific objectives of this research support the Arctic and Global Prediction Program and the Ocean Acoustic Program and the Naval Research Laboratory, and would include the Stratified Ocean Dynamics of the Arctic (SODA), Arctic Mobile Observing System (AMOS), Ocean Acoustics field work (including the Coordinated Arctic Active Tomography Experiment or CAATEX), Naval Research Laboratory experiments, and on-ice measurements for the Sea Ice Dynamics Experiment (SIDEx). These experiments would collect data on water properties (temperature and salinity), stratification, and circulation. The equipment and platforms that would be used during the studies include research vessels (e.g., U.S. Coast Guard Cutter *Healy*), and surface and unmanned underwater vehicles such as gliders; moored and drifting acoustic sources such as the VLF source; other acoustic sources such as an ADCP, chirp sonar, Conductivity Temperature Depth (CTD) echosounder; drifting and moored oceanographic sensors; fixed and towed receiving arrays; aircraft and unmanned air vehicles; on-ice measurements systems; bottom interaction systems including cores; and weather balloons.

Ice Exercises (ICEXs) are also conducted by the Navy ever two to three years north of Alaska (U.S. Navy 2019b). These exercises include the construction of on-ice camps to support submarine training and testing, including torpedo training exercises and the use of active sonar. Other equipment and platforms include manned and unmanned aircraft, unmanned underwater vehicles, buoys and acoustic arrays, divers, and weather balloons. These exercises were last conducted in the Arctic during 2020.

4.1.6.3 Vessel Traffic

Uelen, Russia, is one of the largest ports on the Chukchi Sea. The largest ports on the U.S. coast of the Chukchi Sea is Utqiaġvik and Kivalina; the latter is a port for bulk carriers, cargo vessels, and container ships for a large iron ore mine. The largest U.S. port on the Beaufort Sea is Prudhoe Bay, which receives some industrial cargo vessels. Nonetheless, there would be very limited vessel traffic in the proposed offshore survey area. However, some commercial fishing, U.S. Navy, or research vessels could occur there. Two tankers occurred within the Chukchi Sea when live vessel traffic information (MarineTraffic 2021) was accessed on 14 January 2021, but no vessels occurred within the proposed survey area.

4.1.6.4 Fisheries Interactions

The commercial fisheries in the general area of the proposed survey are described in § 3.6. The primary contributions of fishing to potential cumulative impacts on marine mammals involve noise, potential entanglement, and removal of prey items (e.g., Reeves et al. 2003). Entanglement in fishing gear can lead to serious injury or mortality of some marine mammals. Section 118 of the MMPA requires all commercial fisheries to be placed in one of three categories based on the level of incidental take of marine mammals relative to the Potential Biological Removal (PBR) for each marine mammal stock. Category I, II, and III fisheries are those for which the combined take is ≥50%, 1%–50%, and <1%, respectively, of PBR for a particular stock. In 2019, numerous fisheries were listed as Category II, including: (1) Alaska Bristol Bay salmon gillnet fisheries, due to beluga whale, gray whale, and spotted seal mortalities, among other species; (2) Alaska Peninsula/Aleutian Islands salmon gillnet fisheries, because of harbor porpoise and other mortalities; (3) Alaska Bering Sea, Aleutian Islands trawl fisheries for flatfish, pollock, and rockfish, due to mortalities of several species of pinnipeds, as well as harbor porpoise, humpback whale, gray whale, and killer whale; and (4) Alaska Bering Sea, Aleutian Islands Pacific cod pot fishery, due to mortalities of harbor seals and humpback whales (86 FR 3028). Some additional Alaska gillnet, troll, trawl, pot, hook-and-line, and longline fisheries are listed as Category III.

The highest mean annual mortality rate of any baleen whale in Alaska attributable to commercial fisheries is the humpback whale, with rates of 1.9 mortalities for the Western North Pacific stock and 9.5 mortalities for the Central North Pacific stock (Muto et al. 2020). Mean annual morality rates for Alaska resident and transient killer whales was estimated at 1; for the Bering Sea stock of harbor porpoise, fin whale, and beluga whale, the mean annual mortality rate was 0.2 (Muto et al. 2020). The mean annual mortality rates attributable to commercial fisheries in Alaska have been estimated at 2.4 for ringed seal, 1.6 for bearded seal, 1.1 for ribbon seal, and 0.9 for spotted seal (Muto et al. 2020). The estimated mean mortality for walrus is 2 per year (Muto et al. 2020).

Entanglement in fishing gear and hooking can also lead to mortality of seabirds. From 2010 to 2014, six short-tailed albatross mortalities were reported during commercial fishing activities in Alaska during both hook-and-line and longline fishing (Good et al. 2019). No mortalities occurred from 2015 through 2019 (NOAA 2021f). During 2020, two short tailed albatross were taking in the Bering Sea/Aleutian Islands Management Area during the Pacific cod demersal longline fishery (NOAA 2021f). Bycatch of marbled murrelet in Alaska gillnet fisheries may be substantial, on the order of hundreds of birds annually, and was listed as the second most important human cause for this species' decline in its 2006 Alaska status review (Piatt et al. 2007).

4.1.7 Unavoidable Impacts

Unavoidable impacts to the species of marine mammals 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 on the populations to which they belong; however, NSF requests Level A takes because it estimates takes per the NOAA *Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing*. Effects on recruitment or survival would be expected to be (at most) negligible.

4.1.8 Coordination with Other Agencies and Processes

This Draft EA was prepared by LGL on behalf of the University of Alaska and NSF pursuant to NEPA and 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 process with NMFS and USFWS, EFH consultation, and other regulatory processes. This document will also be used as supporting documentation for an IHA application submitted by the University of Alaska, on behalf of itself, and NSF, to NMFS, under the U.S. MMPA, for "taking by harassment" (disturbance) of small numbers of marine mammals, for the proposed seismic surveys. It will also be used to meet any MMPA requirements under USFWS jurisdiction for walrus and polar bears.

Dr. Coakley has presented the Proposed Action to the Alaska Eskimo Whaling Commission (AEWC) at the July 2020, October 2020, and February 2021 Triannual Meetings. As specifically noted, during the meetings, daily email communications with interested community members would be made from the vessel. Communication may include notice of any unusual marine mammal observations during the Proposed Action. Any potential space use conflicts would be further avoided through direct communication with subsistence fishers/hunters during the surveys; however, due to the significant distance from shore, no direct interaction with subsistence fishers/hunters would be anticipated.

4.2 No Action Alternative

An alternative to conducting the proposed activity is the "No Action" Alternative, i.e., do not issue an IHA and do not conduct the operations. If the research were not conducted, the "No Action" alternative would result in no disturbance to marine mammals attributable to the proposed activity; however, valuable data about the marine environment would be lost. Geological data of scientific value and relevance regarding the constraints on basin history and crustal structure of the Amerasia Basin, information that could be useful for a U.S. claim of an extended continental shelf for seabed resources under Article 76 of the Law of the Sea, and data needed for a potential future IODP project, would not be collected. The No Action Alternative would not meet the purpose and need for the proposed activity.

V LIST OF PREPARERS

LGL Ltd., environmental research associates

Meike Holst, M.Sc., Sidney, BC*

Darren Ireland, M.Sc., Bryan, TX

Colin Jones, B.Sc., St. John's, NL

Tony Lang, Ph.D., St. John's, NL

Gemma Rayner, M.Sc., St. John's, NL

W. John Richardson, Ph.D., King City, ON

Lamont-Doherty Earth Observatory

Anne Bécel, Ph.D., Palisades, NY

Sean Higgins, Ph.D., Palisades, NY

National Science Foundation

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

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

VI LITERATURE CITED

Aagaard, K. 1989. A synthesis of the Arctic Ocean circulation. **Rapp. Proc. Reun. Cons. Int. Explor. Mer** 188:11-22.

Aars, J., N.J. Lunn, and A.E. Derocher (eds.) 2006. Polar bears: proceedings of the 14th working meeting of the IUCN/SSC Polar Bear Specialist Group, 20–24 June, Seattle, WA, USA. IUCN, Gland, Switzerland. 189 p.

Aarts, G., A.M. von Benda-Beckmann, K. Lucke, H.Ö. Sertlek, R. Van Bemmelen, S.C. Geelhoed, S. Brasseur, M. Scheidat, F.P.A. Lam, H. Slabbekoorn, and R. Kirkwood. 2016. Harbour porpoise movement strategy affects cumulative number of animals acoustically exposed to underwater explosions. **Mar. Ecol. Prog. Ser.** 557:261-275.

Acosta, A., N. Nino-Rodriquez, M.C. Yepes, and O. Boisseau. 2017. Mitigation provisions to be implemented for marine seismic surveying in Latin America: a review based on fish and cetaceans. **Aquat. Biol.** 199-216.

Aerts, L.A., A.E. McFarland, B.H. Watts, K.S. Lomac-MacNair, P.E. Seiser, S.S. Wisdom, A.V. Kirk, and C.A. Schudel. 2013. Marine mammal distribution and abundance in an offshore sub-region of the northeastern Chukchi Sea during the open-water season. **Cont. Shelf Res.** 67:116-126.

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

Aguilar de Soto, N. 2016. Peer-reviewed studies on the effects of anthropogenic noise on marine invertebrates: from scallop larvae to giant squid. p. 17-26 *In*: The effects of noise on aquatic life II, Springer, New York, NY. 1292 p.

Aguilar de Soto, N., N. Delorme, J. Atkins, S. Howard, J. Williams, and M. Johnson. 2013. Anthropogenic noise causes body malformations and delays development in marine larvae. **Sci. Rep.** 3:2831. http://dx.doi.org/doi:10.1038/srep02831.

Aguilar Soto, N., M. Johnson, P.T. Madsen, P.L. Tyack, A. Bocconcelli, and J.F. Borsani. 2006. Does intense ship noise disrupt foraging in deep-diving Cuvier's beaked whales (*Ziphius cavirostris*)? **Mar. Mamm. Sci.** 22(3):690-699.

ADF&G (Alaska Department of Fish and Game). 2021. State of Alaska Species Status Species, State of Alaska Endangered Species. Accessed Janaury 2021 at http://www.adfg.alaska.gov/index.cfm?adfg=specialstatus.akendangered.

Amstrup, S.C. 1995. Movements, distribution, and population dynamics of polar bears in the Beaufort Sea. Ph.D. Dissertation. Univ. Alaska–Fairbanks, Fairbanks, AK. 299 p.

Amstrup, S.C., I. Stirling, and J.W. Lentfer. 1986. Past and present status of polar bears in Alaska. **Wildl. Soc. Bull.** 14(3):241-254.

Anderwald, P., A. Brandecker, M. Coleman, C. Collins, H. Denniston, M.D. Haberlin, M. O'Donovan, R. Pinfield, F. Visser, and L. Walshe. 2013. Displacement responses of a mysticete, an odontocete, and a phocid seal to construction-related vessel traffic. **Endang. Species Res.** 21(3):231-240.

Andrews, C.D., J.F. Payne, and M.L. Rise. 2014. Identification of a gene set to evaluate the potential effects of loud sounds from seismic surveys on the ears of fishes: a study with *Salmo salar*. **J. Fish Biol.** 84(6):1793-1819.

Atkinson, S., D. Crocker, D. Houser, and K. Mashburn. 2015. Stress physiology in marine mammals: How well do they fit the terrestrial model? **J. Comp. Physiol. B** 185(5):463-486.

Azzara, A.J., W.M. von Zharen, and J.J. Newcomb. 2013. Mixed-methods analytic approach for determining potential impacts of vessel noise on sperm whale click behavior. **J. Acoust. Soc. Am.** 134(6):4566-4574.

Bain, D.E. and R. Williams. 2006. Long-range effects of airgun noise on marine mammals: responses as a function of received sound level and distance. Working Pap. SC/58/E35. Int. Whal. Comm., Cambridge, UK. 13 p.

Baker, C.S. and L.M. Herman. 1989. Behavioral responses of summering humpback whales to vessel traffic: experimental and opportunistic observations. NPS-NR-TRS-89-01. Rep. from Kewalo Basin Mar. Mamm. Lab., Univ. Hawaii, Honolulu, HI, for U.S. Natl. Park Serv., Anchorage, AK. 50 p. NTIS PB90-198409.

Baker, C.S., L.M. Herman, B.G. Bays, and W.F. Stifel. 1982. The impact of vessel traffic on the behavior of humpback whales in southeast Alaska. Rep. from Kewalo Basin Mar. Mamm. Lab., Honolulu, HI, for U.S. Natl. Mar. Fish. Serv., Seattle, WA. 78 p.

Baker, C.S., L.M. Herman, B.G. Bays, and G.B. Bauer. 1983. The impact of vessel traffic on the behavior of humpback whales in southeast Alaska: 1982 season. Rep. from Kewalo Basin Mar. Mamm. Lab., Honolulu, HI, for U.S. Nat. Mar. Mamm. Lab., Seattle, WA. 30 p.

Barlow, J. 1988. Harbor porpoise, *Phocoena*, abundance estimation for California, Oregon, and Washington: I. Ship surveys. **Fish. Bull.** 86(3):417-432.

Barry, S.B., A.C. Cucknell, and N. Clark. 2012. A direct comparison of bottlenose dolphin and common dolphin behaviour during seismic surveys when airguns are and are not being utilised. p. 273-276 *In*: A.N. Popper and A. Hawkins (eds.), The effects of noise on aquatic life. Springer, New York, NY. 695 p.

Beland, J. and D. Ireland. 2010. Marine mammal monitoring and mitigation during a geophysical survey in the Arctic Ocean, August–September 2010: 90-day report. LGL Rep. P1123-1. Rep. from LGL Alaska Research Associates, Inc., for U.S. Geological Survey, Menlo Park, CA, Nat. Mar. Fish. Serv., Silver Spring, MD, and US Fish and Wild. Serv., Anchorage, AK. 145 p.

Belkin, I., M.C. Aquarone, and S. Adams. 2009. XI-29 Arctic Ocean LME. p. 455-461 *In:* K. Sherman and G. Hempel (eds.) The UNEP Large Marine Ecosystem Report: a perspective on changing conditions in LMEs of the worlds regional seas. UNEP Regional Seas Report and Studies No. 182. United Nations Environment Programme. Nairobi, Kenya.

Bengtson, J.L., L.M. Hiruki-Raring, M.A. Simpkins, and P.L. Boveng. 2005. Ringed and bearded seal densities in the eastern Chukchi Sea, 1999-2000. **Polar Biol.** 28:833-845-230.

Bernstein, L. 2013. The Washington Post: health, science, and environment. Panel links underwater mapping sonar to whale stranding for first time. Published 6 October 2013. Accessed January 2021 at https://www.washingtonpost.com/national/health-science/panel-links-underwater-mapping-sonar-to-whale-stranding-for-first-time/2013/10/06/52510204-2e8e-11e3-bbed-a8a60c601153_story.html

Bettridge, S., C.S. Baker, J. Barlow, P.J. Clapham, M. Ford, D. Gouveia, D.K. Mattila, R.M. Pace, III, P.E. Rosel, G.K. Silber, and P.R. Wade. 2015. Status review of the humpback whale (*Megaptera novaeangliae*) under the Endangered Species Act. NOAA Tech. Memo. NMFS-SWFSC-540. Nat. Mar. Fish. Service, Southwest Fish. Sci. Center, La Jolla, CA. 240 p.

Birdlife International. 2021. Species factsheet: *Phoebastria albatrus*. Accessed in January 2021 at http://www.birdlife.org.

Bittencourt, L., I.M.S. Lima, L.G. Andrade, R.R. Carvalho, T.L. Bisi, J. Lailson-Brito, Jr., and A.F. Azevedo. 2016. Underwater noise in an impacted environment can affect Guiana dolphin communication. **Mar. Poll. Bull.** 114(2):1130-1134.

Blackwell, S.B., R.G. Norman, C.R. Greene Jr., M.W. McLennan, T.L. McDonald, and W.J. Richardson. 2004. Acoustic monitoring of bowhead whale migration, autumn 2003. p. 71-744 *In*: W.J. Richardson and M.T. Williams (eds.), Monitoring of industrial sounds, seals, and bowhead whales near BP's Northstar oil development, Alaskan Beaufort Sea, 1999–2003. [Dec. 2004 ed.] LGL Rep. TA4002. Rep. from LGL Ltd., King City, Ont., Greeneridge Sciences Inc., Santa Barbara, CA, and WEST Inc., Cheyenne, WY, for BP Explor. (Alaska) Inc., Anchorage, AK. 297 p. + Appendices A - N on CD-ROM.

Blackwell, S.B., C.R. Greene, Jr., T.L. McDonald, M.W. McLennan, C.S. Nations, R.G. Norman, and A. Thode. 2010. Beaufort Sea acoustic monitoring program. Chapter 8 *In*: D.W. Funk, R. Rodrigues, D.S. Ireland, and W.R. Koski (eds.), Joint monitoring program in the Chukchi and Beaufort seas, open water seasons, 2006–2008. LGL Alaska Rep. P1050-2. Rep. from LGL Alaska Research Associates, Inc., LGL Ltd., Greeneridge Sciences, Inc., and JASCO Research, Ltd., for Shell Offshore, Inc. and other Industry contributors, National Marine Fisheries Service, and U.S. Fish and Wildlife Service. 506 p. + app.

Blackwell, S.B., C.S. Nations, T.L. McDonald, C.R. Greene, Jr., A.M. Thode, M. Guerra, and A.M. Macrander. 2013. Effects of airgun sounds on bowhead whale calling rates in the Alaskan Beaufort Sea. **Mar. Mamm. Sci.** 29(4):E342-E365.

Blackwell, S.B., C.S. Nations, T.L. McDonald, A.M. Thode, D. Mathias, K.H. Kim, C.R. Greene, Jr., and A.M. Macrander. 2015. Effects of airgun sounds on bowhead whale calling rates: evidence for two behavioral thresholds. **PLoS ONE** 10(6):e0125720. http://dx.doi.org/doi:10.1371/journal.pone.0125720.

Blair, H.B., N.D. Merchant, A.S. Friedlaender, D.N. Wiley, and S.E. Parks. 2016. Evidence for ship noise impacts on humpback whale foraging behaviour. **Biol. Lett.** 12:20160005.

Bluhm, B.A., K.O. Coyle, B. Konar, and R. Highsmith. 2007. High gray whale relative abundances associated with an oceanographic front in the south-central Chukchi Sea. **Deep-sea Res. II** 54:2919-2933.

Boveng, P., and M. Cameron. 2013. Pinniped movements and foraging: seasonal movements, habitat selection, foraging and haul-out behavior of adult bearded seals in the Chukchi Sea. Final Report, BOEM Report 2013-01150. Bureau of Ocean Energy Management, Alaska Outer Continental Shelf Region, Anchorage, Alaska. 91 p.

Boveng, P. L., J.L. Bengtson, T.W. Buckley, M.F. Cameron, S.P. Dahle, B.P. Kelly, B.A. Megrey, J.E. Overland, and N.J. Williamson. 2009. Status review of the spotted seal (*Phoca largha*). U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-200, 153 p.

Boveng, P.L., J.L. Bengtson, M.F. Cameron, S.P. Dahle, E.A. Logerwell, J.M. London, J.E. Overland, J.T. Sterling, D.E. Stevenson, B.L. Taylor, and H.L. Ziel. 2013. Status review of the ribbon seal (*Histriophoca fasciata*). U.S. Department of Commerce, NOAA Tech. Memo NMFSAFSC-255. 175 p.

Boveng, P.L., M. Cameron, P.B. Conn, and E. Moreland. 2017. Abundance Estimates of Ice-Associated Seals: Bering Sea Populations that Inhabit the Chukchi Sea During the Open-Water Period. Final Report. BOEM Report 2016-077. Bureau of Ocean Energy Management, Alaska Outer Continental Shelf Region, Anchorage, Alaska, U.S. 199 p.

Braham, H.W. 1984. Distribution and migration of gray whales in Alaska. p. 249-266 *In:* Jones, M.L., S.L. Swartz, and S. Leatherwood (eds.), The gray whale *Eschrichtius robustus*. Academic Press, Orlando, FL. 600 p.

Branstetter, B.K., J.S. Trickey, and H. Aihara. J.J. Finneran, and T.R. Liberman. 2013. Time and frequency metrics related to auditory masking of a 10 kHz tone in bottlenose dolphins (*Tursiops truncatus*). **J. Acoust. Soc. Am.** 134(6):4556-4565.

Branstetter, B.K., K.L. Bakhtiari, J.S. Trickey, and J.J. Finneran. 2016. Hearing mechanisms and noise metrics related to auditory masking in bottlenose dolphins (*Tursiops truncatus*). p. 109-116 *In*: A.N. Popper and A. Hawkins (eds.), The effects of noise on aquatic life II. Springer, New York, NY. 1292 p.

Breitzke, M. and T. Bohlen. 2010. Modelling sound propagation in the Southern Ocean to estimate the acoustic impact of seismic research surveys on marine mammals. **Geophys. J. Int.** 181(2):818-846.

Brower, A.A., J.T. Clarke, and M.C. Ferguson. 2018. Increased sightings of subArctic cetaceans in the eastern Chukchi Sea, 2008-2016: population recovery, response to climate change, or increased survey effort? **Polar Biol.** 41:1033-1039.

Brower, H., Jr. 1996. Observations on locations at which bowhead whales have been taken during the fall subsistence hunt (1988 through 1995) by Eskimo hunters based in Barrow, Alaska. North Slope Borough Dep. Wildl. Manage., Barrow, AK. 8 p. Revised 19 Nov. 1996.

Bröker, K., J. Durinck, C. Vanman, and B. Martin. 2013. Monitoring of marine mammals and the sound scape during a seismic survey in two license blocks in the Baffin Bay, West Greenland, in 2012. p. 32 *In*: Abstr. 20th Bienn. Conf. Biol. Mar. Mamm., 9–13 December 2013, Dunedin, New Zealand. 233 p.

Bröker, K., G. Gailey, J. Muir, and R. Racca. 2015. Monitoring and impact mitigation during a 4D seismic survey near a population of gray whales off Sakhalin Island, Russia. **Endang. Species Res.** 28:187-208.

Bruce, B., R. Bradford, S. Foster, K. Lee, M. Lansdell, S. Cooper, and R. Przeslawski. 2018. Quantifying fish behaviour and commercial catch rates in relation to a marine seismic survey. **Mar. Environ. Res.** http://dx.doi.org/doi:10.1016/j.marenvres.2018.05.005.

Brueggeman, J. 2009. 90–day report of the marine mammal monitoring program for the ConocoPhillips Alaska shallow hazards survey operations during the 2008 open water season in the Chukchi Sea. Rep from Canyon Creek Consulting LLC, Seattle, WA, for ConocoPhillips Alaska, Inc.

Brueggeman, J.J., G.A. Green, K.C. Balcomb, C.E. Bowlby, R.A. Grotefendt, K.T. Briggs, M.L. Bonnell, R.G. Ford, D.H. Varoujean, D. Heinemann, and D.G. Chapman. 1990. Oregon-Washington marine mammal and seabird survey: information synthesis and hypothesis formulation. OCS Study MMS 89-0030. Rep. from Envirosphere Co., Bellevue, WA, and Ecological Consulting Inc., Portland, OR, for U.S. Minerals Manage. Serv., Pacific Region, Los Angeles, CA. 374 p.

Burns, J.J. 1970. Remarks on the distribution and natural history of pagophilic pinnipeds in the Bering and Chukchi Seas. **J. Mammal**. 51(3):445-454.

Burns, J.J. 1981. Bearded seal *Erignathus barbatus* Erxleben, 1777. p. 145-170 *In*: S.H. Ridgway and R.J. Harrison (eds.), Handbook of marine mammals, Vol. 2: Seals. Academic Press, New York, NY. 359 p.

Burns, J.J., L.H. Shapiro, and F.H. Fay. 1981. Ice as marine mammal habitat in the Bering Sea. *In*: D.W. Hoome and J.A. Calder (eds.), The eastern Bering Sea shelf: oceanography and resources, Vol. II. Juneau, AK. OMPA, BLM.

Calambokidis, J., G.H Steiger, K. Rasmussen, J. Urbán R., K.C. Balcomb, P. Ladrón De Guevara, M. Salinas Z., J.K. Jacobsen, C.S. Baker, L.M. Herman, S. Cerchio, and J.D. Darling. 2000. Migratory destinations of humpback whales from the California, Oregon and Washington feeding ground. **Mar. Ecol. Prog. Ser.** 192:295-304.

Calambokidis, J., G.H. Steiger, J.M. Straley, L.M. Herman, S. Cerchio, D.R. Salden, J. Urbán R., J.K. Jacobsen, O. von Ziegesar, K.C. Balcomb, C.M. Gabrielle, M.E. Dahlheim, S. Uchida, G. Ellis, Y. Miyamura, P.L. de Guevara, M. Yamaguchi, F. Sato, S.A. Mizroch, L. Schlender, K. Rasmussen, J. Barlow, and T.J. Quinn II. 2001. Movements and population structure of humpback whales in the North Pacific. **Mar. Mamm. Sci.** 17(4):769-794.

Calambokidis, J., E.A. Falcone, T.J. Quinn, A.M. Burdin, P.J. Clapham, J.K.B. Ford, C.M. Gabriele, R. LeDuc, D. Mattila, L. Rojas-Bracho, J.M. Straley, B.L. Taylor, J. Urban R., D. Weller, B.H. Witteveen, M. Yamaguchi, A. Bendlin, D. Camacho, K. Flynn, A. Havron, J. Huggins, and N. Maloney. 2008. SPLASH: structure of populations, levels of abundance and status of humpback whales in the North Pacific. Rep. AB133F-03-RP-0078 for U.S. Dept. of Comm., Seattle, WA.

Cameron, M., J. London, and P. Boveng. 2009. Polar ecosystems project. Telemetry of ice seals captured during a research cruise aboard the *McArthur II* in the eastern Bering Sea. Accessed January 2021 at https://archive.fisheries.noaa.gov/afsc/Quarterly/amj2009/divrptsNMML3.htm.

Campana, I., R. Crosti, D. Angeletti, L. Carosso, L. Davis, N. Di-Méglio, A. Moulins, M. Rosso, P. Tepsich, and A. Arcangeli. 2015. Cetacean response to summer maritime traffic in the western Mediterranean Sea. **Mar. Environ. Res.** 109:1-8.

Carretta, J.V., K.A. Forney, E.M. Oleson, D.W. Weller, A.R. Lang, J. Baker, M.M. Muto, B. Hanson, A.J. Orr, H. Huber, M.S. Lowry, J. Barlow, J.E. Moore, D. Lynch, L. Carswell, and R.L. Brownwell, Jr. 2019. U.S. Pacific marine mammal stock assessments: 2018. NOAA Tech. Memo. NOAA-TM-NMFS-SWFSC-617. Nat. Mar. Fish. Serv., Southwest Fish. Sci. Center, La Jolla, CA. 377 p.

Carretta, J.V., K.A. Forney, E.M. Oleson, D.W. Weller, A.R. Lang, J. Baker, M.M. Muto, B. Hanson, A.J. Orr, H. Huber, M.S. Lowry, J. Barlow, J.E. Moore, D. Lynch, L. Carswell, and R.L. Brownwell, Jr. 2020. U.S. Pacific marine mammal stock assessments: 2019. NOAA Tech. Memo. NOAA-TM-NMFS-SWFSC-629. Nat. Mar. Fish. Serv., Southwest Fish. Sci. Center, La Jolla, CA. 377 p.

Carroll, A.G., R. Przeslawski, A. Duncan, M. Gunning, and B. Bruce. 2017. A review of the potential impacts of marine seismic surveys on fish & invertebrates. **Mar. Poll. Bull.** 114:9-24.

Castellote, M. and C. Llorens. 2016. Review of the effects of offshore seismic surveys in cetaceans: Are mass strandings a possibility? p. 133-143 *In*: A.N. Popper and A. Hawkins (eds.), The effects of noise on aquatic life II. Springer, New York, NY. 1292 p.

Castellote, M., C.W. Clark, and M.O. Lammers. 2012. Acoustic and behavioural changes by fin whales (*Balaenoptera physalus*) in response to shipping and airgun noise. **Biol. Conserv.** 147(1):115-122.

CBD (Convention on Biological Diversity). 2021. Ecologically or biologically significant marine areas. Accessed January 2021 at https://www.cbd.int/ebsa/

Celi, M., F. Filiciotto, D. Parrinello, G. Buscaino, M.A. Damiano, A. Cuttitta, S. D'Angelo, S. Mazzola, and M. Vazzana. 2013. Physiological and agonistic behavioural response of *Procambarus clarkii* to an acoustic stimulus. **J. Exp. Biol.** 216(4):709-718.

Cerchio, S., S. Strindberg, T. Collins, C. Bennett, and H. Rosenbaum. 2014. Seismic surveys negatively affect humpback whale singing activity off northern Angola. **PLoS ONE** 9(3):e86464. doi:10.1371/journal.pone.0086464.

Cholewiak, D., A. Izzi, D. Palka, P. Corkeron, and S. Van Parijs. 2017. Beaked whales demonstrate a marked acoustic response to the use of shipboard echosounders. Abstract and presentation at the Society for Marine Mammalogy's 22nd Biennial Conference on the Biology of Marine Mammals, 22–27 October, Halifax, NS, Canada.

Cholewiak, D., C.W. Clark, D. Ponirakis, A. Frankel, L.T. Hatch, D. Risch, J.E. Stanistreet, M. Thompson, E. Vu, S.M. Van Parijs. 2018. Communicating amidst the noise: modeling the aggregate influence of ambient and vessel noise on baleen whale communication space in a national marine sanctuary. **Endang. Species Res**. 36:59-75.

Christi, K., C. Lyons, and W.R. Koski. 2010. Beaufort Sea aerial monitoring program. Chapter 7 *In*: D.W. Funk, D.S. Ireland, R. Rodrigues, and W.R. Koski (eds), Joint monitoring program in the Chukchi and Beaufort seas, open water seasons, 2006–2008. LGL Alaska Rep. P1050-2. Rep. from LGL Alaska Research Associates, Inc., LGL Ltd., Greeneridge Sciences, Inc., and JASCO Research, Ltd., for Shell Offshore, Inc. and other Industry contributors, National Marine Fisheries Service, and U.S. Fish and Wildlife Service. 506 p. + app.

Citta, J.J., L.T. Quakenbush, J.C. George, R.J. Small, M.P. Heide-Jørgensen, H. Brower, B. Adams, and L. Brower. 2012. Winter movements of bowhead whales (*Balaena mysticetus*) in the Bering Sea. **Arctic** 65(1):13-34.

Citta, J. J., L.T. Quakenbush, S.R. Okkonen, M.L. Druckenmiller, W. Maslowski, J. Clement-Kinney, J.C. George, H. Brower, R.J. Small, C.J. Ashjian, L.A. Harwood, and M.P. Heide-Jørgensen. 2015. Ecological characteristics of core-use areas used by Bering-Chukchi-Beaufort (BCB) bowhead whales, 2006-2012. **Prog. Oceanogr.** 136:201-222.

Citta, J. J., S. R. Okkonen, L. T. Quakenbush, W. Maslowski, R. Osinski, J. C. George, R. J. Small, H. Brower, Jr., M. P. Heide-Jørgensen, and L. A. Harwood. 2018a. Oceanographic characteristics associated with autumn movements of bowhead whales in the Chukchi Sea. **Deep Sea Res. II.** 152:121-131.

Citta, J.J., L.F. Lowry, L.T. Quakenbush, B.P. Kelly, A.S. Fischbach, J.M. London, C.V. Jay, K.J. Frost, G.O.C. Crowe, J.A. Crawford, P.L. Boveng, M. Cameron, A.L. Von Duyke, M. Nelson, L.A. Harwood, P. Richard, R. Suydam, M.P. Heide-Jørgensen, R.C. Hobbs, D.I. Litovka, M. Marcoux, A. Whiting, A.S. Kennedy, J.C. George, J. Orr, and T. Gray. 2018b. A multi-species synthesis of satellite telemetry data in the Pacific Arctic (1987–2015): Overlap of marine mammal distributions and core use areas. **Deep Sea Res.II: Top. Stud. Oceanog.** 152:132-153.

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

Clapham P.J. and J.G. Mead. 1999. *Megaptera novaeangliae*. **Mamm. Spec.** 604:1-9.

Clark, C.W. and G.C. Gagnon. 2006. Considering the temporal and spatial scales of noise exposures from seismic surveys on baleen whales. Working Pap. SC/58/E9. Int. Whal. Comm., Cambridge, UK. 9 p.

Clark, C.W., W.T. Ellison, B.L. Southall, L. Hatch, S.M. Van Parijs, A. Frankel, and D. Ponirakis. 2009. Acoustic masking in marine ecosystems: intuitions, analysis, and implication. **Mar. Ecol. Prog. Ser.** 395:201-222.

Clarke, J.T., S.E. Moore, and D.K. Ljungblad. 1989. Observations on gray whale (*Eschrichtius robustus*) utilization patterns in the northeastern Chukchi Sea, July–October 1982–1987. **Can. J. Zool**. 67(11):2646-2654.

Clarke, J.T., S.E. Moore, and M.M. Johnson. 1993. Observations on beluga fall migration in the Alaskan Beaufort Sea, 1982–1987, and northeastern Chukchi Sea, 1982–1991. **Rep. Int. Whal. Comm**. 43:387-396.

Clarke, J.T., M.C. Ferguson, C.L. Christman, S.L. Grassia, A.A. Brower, and L.J. Morse. 2011. Chukchi Offshore Monitoring in Drilling Area (COMIDA) Distribution and Relative Abundance of Marine Mammals: Aerial Surveys. Final Report, OCS Study BOEMRE 2011-06. National Marine Mammal Laboratory, Alaska Fisheries Science Center, NMFS, NOAA, 7600 Sand Point Way NE, F/AKC3, Seattle, WA 98115-6349.

Clarke, J.T., M.C. Ferguson, C. Curtice, and J. Harrison. 2015. Biologically important areas for cetaceans within US waters - Arctic region. **Aquat. Mamm. (Special Issue)** 41(1):94-103.

Clarke, J.T., A S. Kennedy, and M.C. Ferguson. 2016. Bowhead and gray whale distributions, sighting rates, and habitat associations in the eastern Chukchi Sea, summer and fall 2009-15, with a retrospective comparison to 1982-91. **Arctic** 69(4):359-377.

Clarke, J.T., A.A. Brower, M.C. Ferguson, and A.L. Willoughby. 2017. Distribution and Relative Abundance of Marine Mammals in the Eastern Chukchi and Western Beaufort Seas, 2016. Annual Report, OCS Study BOEM 2017-078. Marine Mammal Laboratory, Alaska Fisheries Science Center, NMFS, NOAA, 7600 Sand Point Way NE, F/AKC3, Seattle, WA 98115-6349.

Clarke, J.T., A.A. Brower, M.C. Ferguson, and A.L. Willoughby. 2018. Distribution and Relative Abundance of Marine Mammals in the Eastern Chukchi and Western Beaufort Seas, 2017. Annual Report, OCS Study BOEM 2018-023. Marine Mammal Laboratory, Alaska Fisheries Science Center, NMFS, NOAA, 7600 Sand Point Way NE, F/AKC3, Seattle, WA 98115-6349.

Clarke, J.T., A.A. Brower, M.C. Ferguson, and A.L. Willoughby. 2019. Distribution and Relative Abundance of Marine Mammals in the Eastern Chukchi and Western Beaufort Seas, 2018. Annual Report, OCS Study BOEM 2019-021. Marine Mammal Laboratory, Alaska Fisheries Science Center, NMFS, NOAA, 7600 Sand Point Way NE, F/AKC3, Seattle, WA 98115-6349.

Clarke, J.T., A.A. Brower, M.C. Ferguson, A.L. Willoughby, and A.D. Rotrock. 2020. Distribution and Relative Abundance of Marine Mammals in the Eastern Chukchi Sea, Eastern and Western Beaufort Sea, and Amundsen Gulf, 2019. Annual Report, OCS Study BOEM 2020-027. Marine Mammal Laboratory, Alaska Fisheries Science Center, NMFS, NOAA, 7600 Sand Point Way NE, F/AKC3, Seattle, WA 98115-6349.

Conn, P.B., J.M. Ver Hoef, B.T. McClintock, E.E. Moreland, J.M. London, M.F. Cameron, S.P. Dahle, and P.L. Boveng. 2014. Estimating multispecies abundance using automated detection systems: ice-associated seals in the Bering Sea. **Methods Ecol. Evol.** 5:1280-1293.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2004. COSEWIC assessment and update status report on the green sturgeon *Acipenser medirostris* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. vii + 31 p.

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

Costa, D.P., L. Schwarz, P. Robinson, R. Schick, P.A. Morris, R. Condit, D.E. Crocker, and A.M. Kilpatrick. 2016a. A bioenergetics approach to understanding the population consequences of disturbance: elephant seals as a model system. p. 161-169 *In*: A.N. Popper and A. Hawkins (eds.), The effects of noise on aquatic life II. Springer, New York, NY. 1292 p.

Costa, D.P., L.A. Huckstadt, L.K. Schwarz, A.S. Friedlaender, B.R. Mate, A.N. Zerbini, A. Kennedy, and N.J. Gales. 2016b. Assessing the exposure of animals to acoustic disturbance: towards an understanding of the population consequences of disturbance. Proceedings of Meetings on Acoustics 4ENAL 27(1):010027. http://dx.doi.org/doi:10.1121/2.0000298.

Cote, D., C.J. Morris, P.M. Regular, and M.G. Piersiak. 2020. Effects of 2D seismic on snow crab movement behavior. **Fish. Res.** 230:105661.

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

Crowell, S.C. 2016. Measuring in-air and underwater hearing in seabirds. p. 1155-1160 *In*: A.N. Popper and A. Hawkins (eds.), The effects of noise on aquatic life II. Springer, New York, NY. 1292 p.

Culloch, R.M., P. Anderwald, A. Brandecker, D. Haberlin, B. McGovern, R. Pinfield, F. Visser, M. Jessopp, and M. Cronin. 2016. Effect of construction-related activities and vessel traffic on marine mammals. **Mar. Ecol. Prog. Ser.** 549:231-242.

Currie, J.J., S.H. Stack, and G.D. Kaufman. 2017. Modelling whale-vessel encounters: the role of speed in mitigating collisions with humpback whales (*Megaptera novaeangliae*). **J. Cetacean Res. Manage.** 17(1):57-63.

Dahlheim, M. and M. Castellote. 2016. Changes in the acoustic behavior of gray whales *Eschrichtius robustus* in response to noise. **Endang. Species Res.** 31:227-242.

Datsky, A.V. 2015. Fish fauna of the Chukchi Sea and Perspectives of its commercial use. **J. Ichthyol.** 55 (2):185-209.

Davidsen, J.G., H. Dong, M. Linné, M.H. Andersson, A. Piper, T.S. Prystay, E.B. Hvam, E.B. Thorstad, F. Whoriskey, S.J. Cooke, A.D. Sjursen, L. Rønning, T.C. Netland, and A.D. Hawkins. 2019. Effects of sound exposure from a seismic airgun on heart rate, acceleration and depth use in free-swimming Atlantic cod and saithe. **Conserv. Physiol.** 7(1):coz020. http://dx.doi.org/doi:10.1093/conphys/coz020.

Davis, R.A. and C.R. Evans. 1982. Offshore distribution and numbers of white whales in the eastern Beaufort Sea and Amundsen Gulf, summer 1981. Rep. from LGL Ltd., Toronto, Ont., for Sohio Alaska Petrol. Co., Anchorage, AK, and Dome Petrol. Ltd., Calgary, Alb. (co-managers). 76 p.

Day, R.H., T.J. Weingartner, R.R. Hopcroft, L.A.M. Aerts, A. L. Blanchard, A.E. Gall, B.J. Gallaway, D.E. Hannay, B.A. Holladay, J.T. Mathis, B.L. Norcross, J.M. Questral, and S.S. Wisdom. 2013a. The offshore northeastern Chukchi Sea, Alaska: A complex high-latitude ecosystem. **Cont. Shelf Res.** 67:147-165.

Day, R.H., A.E. Gall, T.C. Morgan, J.R. Rose, J.H. Plissner, P.M. Sanzenbacher, J.D. Fenneman, K.J. Kuletz, and B.H. Watts. 2013b. Seabirds new to the eastern Chukchi and Beaufort Seas, Alaska: Response to a changing climate? **Western Birds** 44:174-182.

Day, R.D., R.D. McCauley, Q.P. Fitzgibbon, and J.M. Semmens. 2016a. Seismic air gun exposure during early-stage embryonic development does not negatively affect spiny lobster *Jasus edwardsii* larvae (Decapoda: Palinuridae). **Sci. Rep.** 6:22723.

Day, R.D., R.D. McCauley, Q.P. Fitzgibbon, K. Hartmann and J.M. Semmens. 2016b. Assessing the impact of marine seismic surveys on southeast Australian scallop and lobster fisheries. Fisheries Research & Development Corporation (FRDC). FRDC Project No 2012/008. 144 p.

Day, R.D., R.D. McCauley, Q.P. Fitzgibbon, K. Hartmann and J.M. Semmens. 2017. Exposure to seismic air gun signals causes physiological harm and alters behavior in the scallop *Pecten fumatus*. **PNAS** 114(40):E8537-E8546. doi:10.1073/pnas.1700564114.

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

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

Delarue, J., B. Martin, D. Hannay, and C. Berchok. 2013. Acoustic occurrence and affiliation of fin whales detected in the northeastern Chukchi Sea, July to October 2007–2010. **Arctic** 66(2):159-172.

DeMaster, D.P. and I. Stirling. 1981. *Ursus maritimus*. **Mamm. Species** 145. 7 p.

Deng, Z.D., B.L. Southall, T.J. Carlson, J. Xu, J.J. Martinez, M.A. Weiland, and J.M. Ingraham. 2014. 200-kHz commercial sonar systems generate lower frequency side lobes audible to some marine mammals. **PLoS ONE** 9(4):e95315. doi:10.1371/journal.pone.0095315.

DFO. 2004. Potential impacts of seismic energy on snow crab. DFO Can. Sci. Advis. Sec. Habitat Status Rep. 2004/003.

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

Dohl, T.P., R.C. Guess, M.L. Duman, and R.C. Helm. 1983. Cetaceans of central and northern California, 1980−1983: Status, abundance, and distribution. Final Report to the Minerals Management Service, Contract No. 14-12-0001-29090. 284 p.

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

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

Donovan, C.R., C.M. Harris, L. Milazzo, J. Harwood, L. Marshall, and R. Williams. 2017. A simulation approach to assessing environmental risk of sound exposure to marine mammals. **Ecol. Evol.** 7:2101-2111.

Dorsey, E.M., S.J. Stern, A.R. Hoelzel, and J. Jacobsen. 1990. Minke whale (*Balaenoptera acutorostrata*) from the west coast of North America: individual recognition and small-scale site fidelity. **Rept. Int. Whal. Comm. Spec. Iss.** 12:357-368.

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

Dunlop, R. 2018. The communication space of humpback whale social sounds in vessel noise. Proceedings of Meetings on Acoustics 35(1):010001. doi:10.1121/2.0000935.

Dunlop, R.A., M.J. Noad, R.D. McCauley, E. Kniest, D. Paton, and D.H. Cato. 2015. The behavioural response of humpback whales (*Megaptera novaeangliae*) to a 20 cubic inch air gun. **Aquatic Mamm.** 41(4):412-433.

Dunlop, R.A., M.J. Noad, R.D. McCauley, E. Kniest, R. Slade, D. Paton, and D.H. Cato. 2016a. Response of humpback whales (*Megaptera novaeangliae*) to ramp-up of a small experimental air gun array. **Mar. Poll. Bull.** 103:72-83.

Dunlop, R.A., M.J. Noad, and D.H. Cato. 2016b. A spatially explicit model of the movement of humpback whales relative to a source. Proceedings of Meetings on Acoustics 4ENAL 27(1):010026. doi:10.1121/2.0000296.

Dunlop, R., M.J. Noad, R. McCauley, and D. Cato. 2016c. The behavioral response of humpback whales to seismic air gun noise. **J. Acoust. Soc. Am.** 140(4):3412.

Dunlop, R.A., M.J. Noad, R.D. McCauley, L. Scott-Hayward, E. Kniest, R. Slade, D. Paton, and D.H. Cato. 2017a. Determining the behavioural dose–response relationship of marine mammals to air gun noise and source proximity. **J. Exp. Biol.** 220:2878-2886.

Dunlop, R.A., M.J. Noad, R.D. McCauley, E. Kniest, R. Slade, D. Paton, and D.H. Cato. 2017b. The behavioural response of migrating humpback whales to a full seismic airgun array. **Proc. R. Soc. B** 284:20171901. doi:10.1098/rspb.2017/1901.

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

Dunlop, R.A., R.D. McCauley, and M.J. Noad. 2020. Ships and air guns reduce social interactions in humpback whales at greater ranges than other behavioral impacts. **Mar. Poll. Bull.** 154:111072. doi:10.1016/j.marpolbul.2020.111072.

Durner, G.M. and S.C. Amstrup. 1995. Movements of polar bear from north Alaska to northern Greenland. **Arctic** 48(4):338-341.

Dyndo, M., D.M. Wisniewska, L. Rojano-Doñate, and P.T. Madsen. 2015. Harbour porpoises react to low levels of high frequency vessel noise. **Sci. Rep.** 5:11083. http://dx.doi.org/doi:10.1038/srep11083.

Edmonds, N.J., C.J. Firmin, D. Goldsmith, R.C. Faulkner, and D.T. Wood. 2016. A review of crustacean sensitivity to high amplitude underwater noise: data needs for effective risk assessment in relation to UK commercial species. **Mar. Poll. Bull.** 108 (1-2):5-11.

Edwards, E.F., C. Hall, T.J. Moore, C. Sheredy, and J.V. Redfern. 2015. Global distribution of fin whales *Balaenoptera physalus* in the post-whaling era (1980–2012). **Mamm. Rev.** 45(4):197-214.

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

Ellison, W.T., B.L. Southall, C.W. Clark, and A.S. Frankel. 2012. A new context-based approach to assess marine mammal behavioral responses to anthropogenic sounds. **Conserv. Biol.** 26(1):21-28.

Ellison, W.T., R. Racca, C.W. Clark, B. Streever, A.S. Frankel, E. Fleishman, R. Angliss, J. Berger, D. Ketten, M. Guerra, M. Leu, M. McKenna, T. Sformo, B. Southall, R. Suydam, and L. Thomas. 2016. Modeling the aggregated exposure and responses of bowhead whales *Balaena mysticetus* to multiple sources of anthropogenic underwater sound. **Endang. Species Res.** 30:95-108.

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

Ely, C.R., C.P. Dau, and C.A. Babcock. 1994. Decline in a population of spectacled eiders nesting on the Yukon-Kuskokwim delta, Alaska. **Northw. Nat.** 75:81-87.

Encyclopædia Britannica. 2021. Arctic Ocean. Accessed January 2021 at https://www.britannica.com/place/Arctic-Ocean.

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

Erbe, C. 2012. The effects of underwater noise on marine mammals. p. 17-22 *In*: A.N. Popper and A. Hawkins (eds.), The effects of noise on aquatic life. Springer, New York, NY. 695 p.

Erbe, C., C. Reichmuth, K. Cunningham, K. Lucke, and R. Dooling. 2016. Communication masking in marine mammals: a review and research strategy. **Mar. Poll. Bull.** 103:15-38.

Estes, J.A. and J.R. Gilbert. 1978. Evaluation of an aerial survey of Pacific walruses (*Odobenus rosmarus divergens*). **J. Fish. Res. Board Can.** 35:1130-1140.

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

Farmer, N., K. Baker, D. Zeddies, M. Zykov, D. Noren, L. Garrison, E. Fougeres, and A. Machernis. 2017. Population consequences of disturbance for endangered sperm whales (*Physeter macrocephalus*) exposed to seismic surveys in the Gulf of Mexico, USA. Abstract and presentation at the Society for Marine Mammalogy's 22nd Biennial Conference on the Biology of Marine Mammals, 22–27 October, Halifax, NS, Canada.

Fay, F.H. 1981. Walrus *Odobenus rosmarus* (Linnaeus, 1758). p. 1-23 *In*: S.H. Ridgway and R.J. Harrison (eds.), Handbook of marine mammals, Vol. 1: The walrus, sea lions, fur seals and sea otter. Academic Press, London, U.K. 235 p.

Fay, F.H. 1982. Ecology and biology of the Pacific walrus, *Odobenus rosmarus divergens* Illiger. **North Am. Fauna** 74. 279 p.

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

Ferguson, M.C., C. Curtice, and J. Harrison. 2015a. 7. Biologically important areas for cetaceans within U.S. waters – Aleutian Islands and Bering Sea region. **Aquat. Mamm.** 41(1):73-93.

Ferguson, M.C., C. Curtice, and J. Harrison. 2015b. 6. Biologically important areas for cetaceans within U.S. waters – Gulf of Alaska region. **Aquat. Mamm.** 41(1):65-78.

Fewtrell, J.L. and R.D. McCauley. 2012. Impact of air gun noise on the behaviour of marine fish and squid. **Mar. Poll. Bull.** 64(5):984-993.

Fields, D.M., N.O. Handegard, J. Dalen, C. Eichner, K. Malde, Ø. Karlsen, A.B. Skiftesvik, C.M.F. Durif and H.I. Browman. 2019. Airgun blasts used in marine seismic surveys have limited effects on mortality, and no sublethal effects on behaviour of gene expression, in the copepod *Calanus finmarchicus*. **ICES J. Mar. Sci.** doi:10.1093/icesjms/fsz126.

Finley, K.J. 1982. The estuarine habitat of the beluga or white whale, *Delphinapterus leucas*. **Cetus** 4:4-5.

Finley, K.J., G.W. Miller, R.A. Davis, and W.R. Koski. 1983. A distinctive large breeding population of ringed seals (*Phoca hispida*) inhabiting the Baffin Bay pack ice. **Arctic** 36(2):162-173.

Finneran, J.J. 2012. Auditory effects of underwater noise in odontocetes. p. 197-202 *In*: A.N. Popper and A. Hawkins (eds.), The effects of noise on aquatic life. Springer, New York, NY. 695 p.

Finneran, J.J. 2015. Noise-induced hearing loss in marine mammals: a review of temporary threshold shift studies from 1996 to 2015. **J. Acoust. Soc. Am.** 138(3):1702-1726.

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

Finneran, J.J. and B.K. Branstetter. 2013. Effects of noise on sound perception in marine mammals. p. 273-308 *In*: H. Brumm (ed.), Animal communication and noise. Springer Berlin, Heidelberg, Germany. 453 p.

Finneran, J.J. and C.E. Schlundt. 2010. Frequency-dependent and longitudinal changes in noise-induced hearing loss in a bottlenose dolphin (*Tursiops truncatus*) (L). **J. Acoust. Soc. Am.** 128(2):567-570.

Finneran, J.J. and C.E. Schlundt. 2011. Noise-induced temporary threshold shift in marine mammals. **J. Acoust. Soc. Am.** 129(4):2432. [Supplemented by oral presentation at the ASA meeting, Seattle, WA, May 2011].

Finneran, J.J. and C.E. Schlundt. 2013. Effects of fatiguing tone frequency on temporary threshold shift in bottlenose dolphins (*Tursiops truncatus*). **J. Acoust. Soc. Am.** 133(3):1819-1826.

Finneran, J.J., C.E. Schlundt, D.A. Carder, J.A. Clark, J.A. Young, J.B. Gaspin, and S.H. Ridgway. 2000. Auditory and behavioral responses of bottlenose dolphins (*Tursiops truncatus*) and beluga whales (*Delphinapterus leucas*) to impulsive sounds resembling distant signatures of underwater explosions. **J. Acoust. Soc. Am.** 108(1):417-431.

Finneran, J.J., C.E. Schlundt, R. Dear, D.A. Carder, and S.H. Ridgway. 2002. Temporary shift in masked hearing thresholds in odontocetes after exposure to single underwater impulses from a seismic watergun. **J. Acoust. Soc. Am.** 111(6):2929-2940.

Finneran, J.J., D.A. Carder, C.E. Schlundt, and S.H. Ridgway. 2005. Temporary threshold shift in bottlenose dolphins (*Tursiops truncatus*) exposed to mid-frequency tones. **J. Acoust. Soc. Am.** 118(4):2696-2705.

Finneran, J.J., C.E. Schlundt, D.A. Carder, J.A. Clark, J.A. Young, J.B. Gaspin, and S.H. Ridgway. 2000. Auditory and behavioral responses of bottlenose dolphins (*Tursiops truncatus*) and beluga whales (*Delphinapterus leucas*) to impulsive sounds resembling distant signatures of underwater explosions. **J. Acoust. Soc. Am.** 108(1):417-431.

Finneran, J.J., C.E. Schlundt, R. Dear, D.A. Carder, and S.H. Ridgway. 2002. Temporary shift in masked hearing thresholds in odontocetes after exposure to single underwater impulses from a seismic watergun. **J. Acoust. Soc. Am.** 111(6):2929-2940.

Finneran, J.J., D.A. Carder, C.E. Schlundt, and S.H. Ridgway. 2005. Temporary threshold shift in bottlenose dolphins (*Tursiops truncatus*) exposed to mid-frequency tones. **J. Acoust. Soc. Am.** 118(4):2696-2705.

Finneran, J.J., D.A. Carder, C.E. Schlundt, and R.L. Dear. 2010a. Growth and recovery of temporary threshold shift (TTS) at 3 kHz in bottlenose dolphins (*Tursiops truncatus*). **J. Acoust. Soc. Am.** 127(5):3256-3266.

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

Finneran, J.J., C.E. Schlundt, B.K. Branstetter, J.S. Trickey, V. Bowman, and K. Jenkins. 2015. Effects of multiple impulses from a seismic air gun on bottlenose dolphin hearing and behavior. **J. Acoust. Soc. Am.** 137(4):1634-1646.

FishBase. 2021. Species in the Beaufort Sea. https://www.fishbase.in/TrophicEco/FishEcoList.php?ve_code=121. Accessed 6th January 2021.

Fitzgibbon, Q.P., R.D. Day, R.D. McCauley, C.J. Simon, and J.M. Semmens. 2017. The impact of seismic air gun exposure on the haemolymph physiology and nutritional condition of spiny lobster, *Jasus edsardsii*. **Mar. Poll. Bull.** 125(1-2):146-156.

Flint, P.L. and M.P. Herzog. 1999. Breeding of Steller's eiders, *Polysticta stelleri*, on the Yukon-Kuskokwim delta, Alaska. **Can. Field-Nat.** 113(2):306-308.

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

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

Forney, K.A., B.L. Southall, E. Slooten, S. Dawson, A.J. Read, R.W. Baird, and R.L. Brownell, Jr. 2017. Nowhere to go: noise impact assessments for marine mammal populations with high site fidelity. **Endang. Species Res.** 32:391-413.

Forster, C.E., B.L. Norcross, and I. Spies. 2020. Documenting growth parameters and age in Arctic fish species in the Chukchi and Beaufort seas. **Deep-Sea Res. Part II.** 177: 1-12.

Fredrickson, L.H. 2020. Steller's Eider (*Polysticta stelleri*), version 1.0. *In*: Birds of the World. S. M. Billerman (ed.). Cornell Lab of Ornithology, Ithaca, NY. https://doi.org/10.2173/bow.steeid.01.

Frost, K.J., L.F. Lowry, and J.J. Burns. 1988. Distribution, abundance, migration, harvest, and stock identity of belukha whales in the Beaufort Sea. p. 27-40 *In*: P.R. Becker (ed.), Beaufort Sea (Sale 97) information update. OCS Study MMS 86-0047. Nat. Oceanic & Atmos. Admin., Ocean Assess. Div., Anchorage, AK. 87 p.

Funk, D. W., D. S. Ireland, R. Rodrigues, and W. R. Koski (eds.). 2010. Joint monitoring program in the Chukchi and Beaufort seas, open-water seasons, 2006–2008. LGL Alaska Report P1050-3, Report from LGL Alaska Research Associates, Inc., LGL, Ltd., Greeneridge Sciences, Inc., and JASCO Research, Ltd., for Shell Offshore, Inc. and Other Industry Contributors, and National Marine Fisheries Service, U.S. Fish and Wildlife Service. 499 p. + appendices.

Funk, D.W., C.M. Reiser, D.S. Ireland, R. Rodrigues, and W.R. Koski (eds.). 2011. Joint Monitoring Program in the Chukchi and Beaufort seas, 2006–2010. LGL Alaska Draft Report P1213-1, Report from LGL Alaska Research Associates, Inc., LGL Ltd., Greeneridge Sciences, Inc., and JASCO Research, Ltd., for Shell Offshore, Inc. and Other Industry Contributors, and National Marine Fisheries Service, U.S. Fish and Wildlife Service. 592 p. plus Appendices.

Gailey, G., B. Würsig, and T.L. McDonald. 2007. Abundance, behavior, and movement patterns of western gray whales in relation to a 3-D seismic survey, northeast Sakhalin Island, Russia. **Environ. Monit. Assess.** 134(1-3):75-91.

Gailey, G., O. Sychenko, T. McDonald, R. Racca, A. Rutenko, and K. Bröker. 2016. Behavioural responses of western gray whales to a 4-D seismic survey off northeastern Sakhalin Island, Russia. **Endang. Species Res.** 30:53-71.

Gailey, G., O. Sychenko, A. Rutenko, and R. Racca. 2017. Western gray whale behavioral response to extensive seismic surveys conducted near their feeding grounds. Abstract and presentation at the Society for Marine Mammalogy's 22nd Biennial Conference on the Biology of Marine Mammals, 22–27 October, Halifax, NS, Canada.

Gallagher, C.A., V. Grimm, L.A. Kyhn, C.C. Kinze, and J. Nabe-Nielsen. 2020. Movement and seasonal energetics mediate vulnerability to disturbance in marine mammal populations. **Am. Nat.** 197(3). doi:10.1086/712798.

Gambell, R. 1985. Fin whale *Balaenoptera physalus* (Linnaeus, 1758). p. 171-192 *In*: S.H. Ridgway and R. Harrison (eds.), Handbook of marine mammals, Vol. 3: The sirenians and baleen whales. Academic Press, London, UK. 362 p.

Garlich-Miller, J., J.G. MacCracken, J. Snyder, M.M. Myers, E. Lance, A. Matz, and J.W.Wilder. 2011. Status of the Pacific walrus (*Odobenus rosmarus divergens*). U.S. Fish and Wildlife Service, Marine Mammals Management, Anchorage, AK.

Garner, G.W., S.T. Knick, and D.C. Douglas. 1990. Seasonal movements of adult female polar bears in the Bering and Chukchi Seas. **Int. Conf. Bear Res. Manage.** 8:219-226.

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

Garrigue, C., P.J. Clapham, Y. Geyer, A.S. Kennedy, and A.N. Zerbini. 2015. Satellite tracking reveals novel migratory patterns and the importance of seamounts for endangered South Pacific humpback whales. **R. Soc. Open Sci.** 2:150489. doi:10.1098/rsos.150489.

Gedamke, J. 2011. Ocean basin scale loss of whale communication space: potential impacts of a distant seismic survey. p. 105-106 *In*: Abstr. 19th Bienn. Conf. Biol. Mar. Mamm., 27 Nov.–2 Dec. 2011, Tampa, FL. 344 p.

Gedamke, J., N. Gales, and S. Frydman. 2011. Assessing risk of baleen whale hearing loss from seismic surveys: the effects of uncertainty and individual variation. **J. Acoust. Soc. Am.** 129(1):496-506.

George, J. C., and R. Suydam. Unpubl. manuscript. Recent observations of narwhal in the Chukchi and Beaufort Seas by local hunters, 13 January 2009. 3 p. Available from Marine Mammal Laboratory, Alaska Fisheries Science Center, 7600 Sand Point Way NE, Seattle, WA 98115.

George, J.C., L.M. Philo, K. Hazard, D. Withrow, G.M. Carroll, and R. Suydam. 1994. Frequency of killer whale (*Orcincus orca*) attacks and ship collisions based on scarring on bowhead whales (*Balaena mysticetus*) of the Bering-Chukchi-Beaufort Seas stock. **Arctic** 47(3):247-255.

Gervaise, C., N. Roy, Y. Simard, B. Kinda, and N. Menard. 2012. Shipping noise in whale habitat: characteristics, sources, budget, and impact on belugas in Saguenay-St. Lawrence Marine Park hub. **J. Acoust. Soc. Am.** 132(1):76-89.

Gilbert, J.R. 1989. Aerial census of Pacific walruses in the Chukchi Sea, 1985. **Mar. Mamm. Sci.** 5(1):17-28.

Givens, G.H., S.L. Edmondson, J.C. George, R. Suydam, R.A. Charif, A. Rahaman, D. Hawthorne, B. Tudor, R.A. DeLong, and C.W. Clark. 2016. Horvitz–Thompson whale abundance estimation adjusting for uncertain recapture, temporal availability variation, and intermittent effort. **Environmetrics** 27(3):134-146.

Givens, G.H., J.A. Mocklin, L. Vate Brattström, B.J. Tudor, W.R. Koski, J.E. Zeh, R. Suydam, and J.C. George. 2018. Adult survival rate and 2011 abundance of Bering-Chukchi-Beaufort Seas bowhead whales from photo-identification data over three decades. Unpubl. doc. submitted to Int. Whal. Comm. Scientific Committee (SC/67b/AWMP/01 Rev1). 24 p.

Gomez, C., J.W. Lawson, A.J. Wright, A.D. Buren, D. Tollit, and V. Lesage. 2016. A systematic review on the behavioural responses of wild marine mammals to noise: the disparity between science and policy. **Can. J. Zool.** 94(12):801-819.

Gong, Z., A.D. Jain, D. Tran, D.H. Yi, F. Wu, A. Zorn, P. Ratilal, and N.C. Makris. 2014. Ecosystem scale acoustic sensing reveals humpback whale behavior synchronous with herring spawning processes and re-evaluation finds no effect of sonar on humpback song occurrence in the Gulf of Maine in fall 2006. **PLoS ONE** 9(10):e104733. doi:10.1371/journal.pone.0104733.

Good, T.P., E. Ward, J. Jannot, R. Shama, N. Riley, and J. McVeigh. 2017. Observed and estimated bycatch of short-tailed albatross in U.S. west coast groundfish fisheries 2002-2017. NMFS Report 6 (Electronic Only) June 2019. Accessed February 2021 at https://www.pcouncil.org/documents/2019/06/agenda-item-i-4-a-nmfs-report-6-observed-and-estimated-bycatch-of-short-tailed-albatross-in-u-s-west-coast-groundfish-fisheries-2016-2017-electronic-only.pdf/

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

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

Gray, H. and K. Van Waerebeek. 2011. Postural instability and akinesia in a pantropical spotted dolphin, *Stenella attenuata*, in proximity to operating airguns of a geophysical seismic vessel. **J. Nature Conserv.** 19(6):363-367.

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

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

Greene, C.R., Jr., R.G. Norman, S.B. Blackwell, and A. Thode. 2007. Acoustics research for studying bowhead migration, 2006. Chapter 10 *In* D.S. Ireland, D.W. Funk, R. Rodrigues, and W.R. Koski (eds.), Joint monitoring program in the Chukchi and Beaufort seas, July–November 2006. LGL Rep. P891-2. Rep. by LGL Alaska Research Associates, Inc., Anchorage, AK, and LGL Ltd., King City, Ont., for Shell Offshore Inc., ConocoPhillips Alaska, Inc., GX Technology, the National Marine Fisheries Service, and the U.S. Fish and Wildlife Service.

Gridley, T., S.H. Elwen, G. Rashley, A.B. Krakauer, and J. Heiler. 2016. Bottlenose dolphins change their whistling characteristics in relation to vessel presence, surface behavior and group composition. Proceedings of Meetings on Acoustics 4ENAL 27(1):010030. doi:10.1121/2.0000312.

Guan, S., J.F. Vignola, J.A. Judge, D. Turo, and T.J. Ryan. 2015. Inter-pulse noise field during an arctic shallow-water seismic survey. **J. Acoust. Soc. Am.** 137(4):2212.

Guerra, M., A.M. Thode, S.B. Blackwell, and M. Macrander. 2011. Quantifying seismic survey reverberation off the Alaskan North Slope. **J. Acoust. Soc. Am.** 130(5):3046-3058.

Guerra, M., P.J. Dugan, D.W. Ponirakis, M. Popescu, Y. Shiu, and C.W. Clark. 2016. High-resolution analysis of seismic airgun impulses and their reverberant field as contributors to an acoustic environment. p. 371-379 *In*: A.N. Popper and A. Hawkins (eds.), The effects of noise on aquatic life II. Springer, New York, NY. 1292 p.

Haley, B. 2006. Marine mammal monitoring during University of Texas at Austin's marine geophysical survey of the western Canada Basin, Chukchi Borderland and Mendeleev Ridge, Arctic Ocean, July–August 2006. Rep. from LGL Alaska Research Associates, Inc., Anchorage AK, and LGL Ltd., King City, Ont., for the University of Texas at Austin, the Nat. Mar. Fish. Serv., Silver Springs, MD, and the U.S. Fish and Wildl. Serv., Anchorage, AK.

Haley, B. and D. Ireland. 2006. Marine mammal monitoring during University of Alaska Fairbanks' marine geophysical survey across the Arctic Ocean, August–September 2005. LGL Rep. TA4122-3. Rep. from LGL Ltd., King City, Ont., for Univ. Alaska Fairbanks, Fairbanks, AK, and Nat. Mar. Fish. Serv., Silver Spring, MD. 80 p.

Haley, B., J. Beland, D.S. Ireland, R. Rodrigues, and D.M. Savarese. 2010. Chapter 3 *In*: D.W. Funk, D.S. Ireland, R. Rodrigues, and W.R. Koski (eds.), Joint monitoring program in the Chukchi and Beaufort seas, open water seasons, 2006–2008. LGL Alaska Report P1050-2. Rep. from LGL Alaska Research Associates, Inc., LGL Ld., Greeneridge Sciences, Inc., and JASCO Research, Ltd., for Shell Offshore, Inc. and other Industry contributors, National Marine Fisheries Service, and U.S. Fish and Wildlife Service. 506 p. + app.

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

Halliday, W.D., M.K. Pine, and S.J. Insley. 2020. Underwater noise and Arctic marine mammals: review and policy recommendations. **Environ. Rev.** 28(4):438-448.

Halliday, W.D., S.J. Insley, R.C. Hilliard, T. de Jong, and M.K. Pine. 2017. Potential impacts of shipping noise on marine mammals in the western Canadian Arctic. **Mar. Poll. Bull.** 123:73–82.

Halliday, W.D., K. Scharffenberg, S. MacPhee, R.C. Hilliard, X. Mouy, D. Whalen, L.L. Loseto, and S.J. Insley. 2019. Beluga vocalizations decrease in response to vessel traffic in the Mackenzie River estuary. **Arctic** 72(4):337–346.

Handegard, N.O., T.V. Tronstad, and J.M. Hovem. 2013. Evaluating the effect of seismic surveys on fish—The efficacy of different exposure metrics to explain disturbance. **Can. J. Fish. Aquat. Sci.** 70(9):1271-1277.

Hansen, K.A., A. Maxwell, U. Siebert, O.N. Larsen, and M. Wahlberg. 2017. Great cormorants (*Phalacrocorax carbo*) can detect auditory cues while diving. **Sci. Nat.** 104:45.

Hansen, K.A., A. Hernandez, T.A. Mooney, M.H. Rasmussen, K. Sørensen, and Wahlberg. 2020. The common murre (*Uria aalge*), an auk seabird, reacts to underwater sound. **J. Acoust. Soc. Am.** 147(6):4069-4074.

Harrington, J.J., J. McAllister, and J.M. Semmens. 2010. Assessing the short-term impact of seismic surveys on adult commercial scallops (*Pecten fumatus*) in Bass Srait. Tasmanian Aquaculture and Fisheries Institute, University of Tasmania.

Harris, C.M., L. Thomas, E.A. Falcone, J. Hildebrand, D. Houser, P.H. Kvadsheim, F.-P.A. Lam, P.J.O. Miller, D.J. Moretti, A.J. Read, H. Slabbekoorn, B.L. Southall, P.L. Tyack, D. Wartzok, and V.M. Janik. 2017. Marine mammals and sonar: dose–response studies, the risk-disturbance hypothesis and the role of exposure context. **J. Appl. Ecol.** http://dx.doi.org/doi:10.1111/1365-25664.12955.

Hartin, K.G., C.M. Reiser, D.S. Ireland, R. Rodrigues, D.M.S. Dickson, J. Beland, and M. Bourdon. 2013. Chukchi Sea vessel-based monitoring program. Chapter 3 *In:* D.W. Funk, C.M. Reiser, D.S. Ireland, R. Rodrigues, and W.R. Koski (eds.). 2013. Joint Monitoring Program in the Chukchi and Beaufort seas, 2006–2010. LGL Alaska Report P1213-2, Report from LGL Alaska Research Associates, Inc., LGL Ltd., Greeneridge Sciences, Inc., and JASCO Research, Ltd., for Shell Offshore, Inc. and Other Industry Contributors, and National Marine Fisheries Service, U.S. Fish and Wildlife Service. 592 p.

Harwood, L., S. Innes, P. Norton, and M. Kingsley. 1996. Distribution and abundance of beluga whales in the Mackenzie estuary, southeast Beaufort Sea, and the west Amundsen Gulf during late July 1992. **Can. J. Fish. Aquatic Sci.** 53(10):2262-2273.

Harwood, L.A., F. McLaughlin, R.M. Allen, J. Illasiak, and J. Alikamik. 2005. First-ever marine mammal and bird observations in the deep Canada Basin and Beaufort/Chukchi seas: expeditions during 2002. **Pol. Biol.** 28(3): 250-253.

Harwood, L.A., T.G. Smith, and J.C. Auld. 2012. Fall migration of ringed seals (*Phoca hispida*) through the Beaufort and Chukchi Seas, 2001-02. **Arctic** 65(1):35-44.

Harwood, L.A., T.G. Smith, J.C. George, S.J. Sandstrom, W. Walkusz, and G.J. Divoky. 2015. Change in the Beaufort Sea ecosystem: Diverging trends in body condition and/or production in five marine vertebrate species. **Prog. Oceanogr.** 136:1-11.

Harwood, J., S. King, C. Booth, C. Donovan, R.S. Schick, L. Thomas, and L. New. 2016. Understanding the population consequences of acoustic disturbance for marine mammals. **Adv. Exp. Med. Biol.** 875:417-243.

Hastie, G.D., C. Donovan, T. Götz, and V.M. Janik. 2014. Behavioral responses of grey seals (*Halichoerus grypus*) to high frequency sonar. **Mar. Poll. Bull.** 79(1-2):205-210.

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

Hastings, M.C. and J. Miksis-Olds. 2012. Shipboard assessment of hearing sensitivity of tropical fishes immediately after exposure to seismic air gun emissions at Scott Reef. p. 239-243 *In*: A.N. Popper and A. Hawkins (eds.), The effects of noise on aquatic life. Springer, New York, NY. 695 p.

Hatch, L.T., C.W. Clark, S.M. Van Parijs, A.S. Frankel, and D.W. Ponirakis. 2012. Quantifying loss of acoustic communication space for right whales in and around a U.S. National Marine Sanctuary. **Conserv. Biol.** 26(6):983-994.

Hauser, D.D.W., K.L. Laidre, R.S. Suydam, and P.R. Richard. 2014. Population-specific home ranges and migration timing of Pacific Arctic beluga whales (*Delphinapterus leucas*). **Polar Biol.** 37:1171-1183.

Hauser, D.D.W., K.L. Laidre, K.M. Stafford, H.L. Stern, R.S. Suydam, and P.R. Richard. 2017. Decadal shifts in autumn migration timing by Pacific Arctic beluga whales are related to delayed annual sea ice formation. **Glob. Change Biol.** 23:2206-2217.

Hawkins, A.D. and A.N. Popper. 2017. A sound approach to assessing the impact of underwater noise on marine fishes and invertebrates. **ICES. J. Mar. Sci.** 74(3):635–651.

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

Hawkins, A.D., A.E. Pembroke, and A.N. Popper. 2015. Information gaps in understanding the effects of noise on fishes and invertebrates. **Rev. Fish Biol. Fish.** 25(1):39-64. http://dx.doi.org/doi:10.1007/s11160-014-9369-3.

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

Hay, K.A and A.W. Mansfield. 1989. Narwhal—*Monodon monoceros* Linnaeus, 1758. p. 145-176 *In*: S.H. Ridgway and R Harrison (eds.), Handbook of marine mammals, Vol. 4: River dolphins and the larger toothed whales. Academic Press, London, UK. 442 p.

Hazard, K. 1988. Beluga whale, *Delphinapterus leucas*. p. 195-235 *In*: J.W. Lentfer (ed.), Selected marine mammals of Alaska. Mar. Mamm. Comm., Washington, DC. 275 p. NTIS PB88-178462.

Heide-Jørgensen, M.P., R.G. Hansen, S. Fossette, N.J. Nielsen, M.V. Jensen, and P. Hegelund. 2013a. Monitoring abundance and hunting of narwhals in Melville Bay during seismic surveys. September 2013. Greenland Institute of Natural Resources. 56 p.

Heide-Jørgensen, M.P., R.G. Hansen, K. Westdal, R.R. Reeves, and A. Mosbech. 2013b. Narwhals and seismic exploration: Is seismic noise increasing the risk of ice entrapments? **Biol. Conserv.** 158:50-54.

Heiler, J., S.H. Elwen, H.J. Kriesell, and T. Gridley. 2016. Changes in bottlenose dolphin whistle parameters related to vessel presence, surface behaviour and group composition. **Animal Behav.** 117:167-177.

Hermannsen, L., J. Tougaard, K. Beedholm, J. Nabe-Nielsen, and P.T. Madsen. 2014. High frequency components of ship noise in shallow water with a discussion of implications for harbor porpoises (*Phocoena phocoena*). **J. Acoust. Soc. Am.** 136(4):1640-1653.

Hermannsen, L., K. Beedholm, J. Tougaard, and P.T. Madsen. 2015. Characteristics and propagation of airgun pulses in shallow water with implications for effects on small marine mammals. **PLoS ONE** 10(7):e0133436. doi:10.1371/journal.pone.0133436.

Heyning, J.E. and M.E. Dahlheim. 1988. *Orcinus orca.* **Mammal. Spec.** 304:1-9.

Heyward, A., J. Colquhoun, E. Cripps, D. McCorry, M. Stowar, B. Radford, K. Miller, I. Miller, and C. Battershill. 2018. No evidence of damage to the soft tissue or skeletal integrity of mesophotic corals exposed to a 3D marine seismic survey. **Mar. Poll. Bull.** 129(1):8-13.

Hodges, J.I. and W.D. Eldridge. 2001. Aerial surveys of eiders and other waterbirds on the eastern Arctic coast of Russia. **Wildfowl** 52:127-142.

Hoelzel, A.R., A. Natoli, M. Dahlheim, C. Olavarria, R. Baird and N. Black. 2002. Low worldwide genetic diversity in the killer whale (*Orcinus orca*): implications for demographic history. **Proc. R. Soc. Lond.** 269:1467-1473.

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

Holt, M.M., D.P. Noren, R.C. Dunkin, and T.M. Williams. 2015. Vocal performance affects metabolic rate in dolphins: implications for animals communicating in noisy environments. **J. Exp. Biol.** 218(11):1647-1654. doi:10.1242/jeb.122424.

Holt, M.M., J.B. Tennessen, E.J. Ward, M.B. Hanson, C.K. Emmons, D.A. Giles, and J.T. Hogan. 2021. Effects of vessel distance and sex on the behavior of endangered killer whales. **Front. Mar. Sci.** 7:1211.

Houghton, J., M.M. Holt, D.A. Giles, M.B. Hanson, C.K. Emmons, J.T. Hogan, T.A. Branch, and G.R. VanBlaricom. 2015. The relationship between vessel traffic and noise levels received by killer whales (*Orcinus orca*). **PLoS ONE** 10(12): e0140119. doi:10.1371/journal.pone.0140119.

Houser, D.S., C.D. Champagne, D.E. Crocker. N.M. Kellar, J. Cockrem, T. Romano, R.K. Booth, and S.K. Wasser. 2016. Natural variation in stress hormones, comparisons across matrices, and impacts resulting from induced stress in the bottlenose dolphin. p. 467-471 *In*: A.N. Popper and A. Hawkins (eds.), The effects of noise on aquatic life II. Springer, New York, NY. 1292 p.

Houser, D.S., W. Yost, R. Burkhard, J.J. Finneran, C. Reichmuth, and J. Mulsow. 2017. A review of the history, development and application of auditory weighting functions in humans and marine mammals. **J. Acoust. Soc. Am.** 141(1371). doi:10.1121/1.4976086.

Hovem, J.M., T.V. Tronstad, H.E. Karlsen, and S. Løkkeborg. 2012. Modeling propagation of seismic airgun sounds and the effects on fish behaviour. **IEEE J. Ocean. Eng.** 37(4):576-588.

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

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

Hunt, G.L., A.L. Blanchard, P. Boveng, P. Dalpadado, K.F. Drinkwater, L. Eisner, R.R. Hopcroft, K.M. Kovacs, B.L. Norcross, P. Renaud, M. Reigstad, M. Renner, H.R. Skjoldal, A. Whitehouse, and R.A. Woodgate. 2013. The Barents and Chukchi Seas: Comparison of two Arctic shelf ecosystems. **J. Mar. Sci.** 109-110:43-68.

Huntington, H.P., and L.T. Quakenbush. 2009. Traditional knowledge of bowhead whale migratory patterns near Kaktovik and Barrow, Alaska. Rep. to the Alaska Eskimo Whaling Commission. 13 p.

Ice Seal Committee. 2019. The subsistence harvest of ice seals in Alaska – a compilation of existing information, 1960-2017. http://www.north-slope.org/departments/wildlifemanagement/co-management-organizations/ice-seal-committee.

IUCN (The World Conservation Union). 2020. The IUCN Red List of Threatened Species. Version 2020-2. Accessed January 2021 at http://www.iucnredlist.org/.

IUCN/SSC PBSG (Polar Bear Specialist Group). 2019. Summary of polar bear population status per 2019. Available at http://pbsg.npolar.no/en/status/status-table.html.

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

IWC. 2021. Population (abundance) estimates. Accessed January 2021 at https://iwc.int/estimate.

Jackson, J.A., D.J. Steel, P. Beerli, B.C. Congdon, C. Olavarría, M.S. Leslie, C. Pomilla, H. Rosenbaum, and C.S. Baker. 2014. Global diversity and oceanic divergence of humpback whales (*Megaptera novaeangliae*). **Proc. R. Soc. B** 281:20133222. doi:10.1098/rspb.2013.3222.

Jay, C.V., B.G. Marcot, and D.C. Douglas. 2011. Projected status of the Pacific walrus (*Odobenus rosmarus divergens*) in the twenty-first century. **Polar Biol.** 34:1065-1084.

Jefferson, T.A., M.A. Webber, and R.L. Pitman. 2015. Marine mammals of the world: a comprehensive guide to their identification, 2nd edit. Academic Press, London, U.K. 608 p.

Jensen, F.H., L. Bejder, M. Wahlberg, N. Aguilar Soto, M. Johnson, and P.T. Madsen. 2009. Vessel noise effects on delphinid communication. **Mar. Ecol. Prog. Ser.** 395:161-175.

Johansen, S., O.N. Larsen, J. Christensen-Dalsgaard, L. Seidelin, T. Huulvej, K. Jensen, S.-G. Linneryrd, M. Boström, and M. Wahlberg. 2016. In-air and underwater hearing in the great cormorant (*Phalacrocorax carbo sinensis*). p. 505-512 *In*: A.N. Popper and A. Hawkins (eds.), The effects of noise on aquatic life II. Springer, New York, NY. 1292 p.

Johnson, S.R. 1979. Fall observations of westward migrating white whales (*Delphinapterus leucas*) along the central Alaskan Beaufort Sea coast. **Arctic** 32(3):275-276.

Johnson, S.R., W.J. Richardson, S.B. Yazvenko, S.A. Blokhin, G. Gailey, M.R. Jenkerson, S.K. Meier, H.R. Melton, M.W. Newcomer, A.S. Perlov, S.A. Rutenko, B. Würsig, C.R. Martin, and D.E. Egging. 2007. A western gray whale mitigation and monitoring program for a 3-D seismic survey, Sakhalin Island, Russia. **Environ. Monit. Assess.** 134(1-3):1-19.

Jones, E.L., G.D. Hastie, S. Smout, J. Onoufriou, N.D. Merchant, K.L. Brookes, and D. Thompson. 2017. Seals and shipping: quantifying population risk and individual exposure to vessel noise. **J. Appl. Ecol.** doi:10.1111/1365-2664.12911.

Jones, M.L. and S.L. Swartz. 1984. Demography and phenology of gray whales and evaluation of whale-watching activities in Laguna San Ignacio, Baja California Sur, Mexico. p. 309-374 *In*: M. L. Jones et al. (eds.), The gray whale *Eschrichtius robustus*. Academic Press, Orlando, FL. 600 p.

Kaschner, K. 2004. Modelling and mapping resource overlap between marine mammals and fisheries on a global scale. University of British Columbia.

Kaschner, K., R. Watson, A. Trites, and D. Pauly. 2006. Mapping world-wide distributions of marine mammal species using a relative environmental suitability (RES) model. **Mar. Ecol. Prog. Ser.** 316:285-310.

Kastak, D. and C. Reichmuth. 2007. Onset, growth, and recovery of in-air temporary threshold shift in a California sea lion (*Zalophus californianus*). **J. Acoust. Soc. Am.** 122(5):2916-2924.

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

Kastak, D., B.L. Southall, R.J. Schusterman, and C. Reichmuth. 2005. Underwater temporary threshold shift in pinnipeds: effects of noise level and duration. **J. Acoust. Soc. Am.** 118(5):3154-3163.

Kastak, D., J. Mulsow, A. Ghoul, and C. Reichmuth. 2008. Noise-induced permanent threshold shift in a harbor seal. **J. Acoust. Soc. Am.** 123(5):2986.

Kastelein, R., R. Gransier, L. Hoek, and J. Olthuis. 2012a. Temporary threshold shifts and recovery in a harbor porpoise (*Phocoena phocoena*) after octave-band noise at 4 kHz. **J. Acoust. Soc. Am.** 132(5):3525-3537.

Kastelein, R.A., R. Gransier, L. Hoek, A. Macleod, and J.M. Terhune. 2012b. Hearing threshold shifts and recovery in harbor seals (*Phoca vitulina*) after octave-band noise exposure at 4 kHz. **J. Acoust. Soc. Am.** 132(4):2745-2761.

Kastelein, R.A., R. Gransier, L. Hoek, and C.A.F. de Jong. 2012c. The hearing threshold of a harbor porpoise (*Phocoena phocoena*) for impulsive sounds (L). **J. Acoust. Soc. Am.** 132(2):607-610.

Kastelein, R.A., N. Steen, R. Gransier, and C.A.F. de Jong. 2013a. Brief behavioral response threshold level of a harbor porpoise (*Phocoena phocoena*) to an impulsive sound. **Aquat. Mamm.** 39(4):315-323.

Kastelein, R.A., R. Gransier, and L. Hoek, and M. Rambags. 2013b. Hearing frequency thresholds of a harbour porpoise (*Phocoena phocoena*) temporarily affected by a continuous 1.5-kHz tone. **J. Acoust. Soc. Am.** 134(3):2286-2292.

Kastelein, R., R. Gransier, and L. Hoek. 2013c. Comparative temporary threshold shifts in a harbour porpoise and harbour seal, and severe shift in a seal. **J. Acoust. Soc. Am.** 134(1):13-16.

Kastelein, R.A., L. Hoek, R. Gransier, M. Rambags, and N. Clayes. 2014. Effect of level, duration, and inter-pulse interval of 1–2 kHz sonar signal exposures on harbor porpoise hearing. **J. Acoust. Soc. Am.** 136:412-422.

Kastelein, R.A., R. Gransier, J. Schop, and L. Hoek. 2015a. Effects of exposure to intermittent and continuous 6-7 kHz sonar sweeps on harbor porpoise (*Phocoena phocoena*) hearing. **J. Acoust. Soc. Am.** 137(4):1623-1633.

Kastelein, R.A., R. Gransier, M.A.T. Marijt, and L. Hoek. 2015b. Hearing frequency thresholds of harbor porpoises (*Phocoena phocoena*) temporarily affected by played back offshore pile driving sounds. **J. Acoust. Soc. Am.** 137(2):556-564.

Kastelein, R.A., R. Gransier, and L. Hoek. 2016a. Cumulative effects of exposure to continuous and intermittent sounds on temporary hearing threshold shifts induced in a harbor porpoise (*Phocoena phocoena*). p. 523-528 *In*: A.N. Popper and A. Hawkins (eds.), The effects of noise on aquatic life II. Springer, New York, NY. 1292 p.

Kastelein, R.A., L. Helder-Hoek, J. Covi, and R. Gransier. 2016b. Pile driving playback sounds and temporary threshold shift in harbor porpoises (*Phocoena phocoena*): effect of exposure duration. **J. Acoust. Soc. Am.** 139(5):2842-2851.

Kastelein, R.A., L. Helder-Hoek, S. Van de Voorde, A.M. von Benda-Beckmann, F.P.A. Lam, E. Jansen, C.A.F. de Jong, and M.A. Ainslie. 2017. Temporary hearing threshold shift in a harbor porpoise (*Phocoena phocoena*) after exposure to multiple airgun sounds. **J. Acoust. Soc. Am.** 142(4):2430-2442.

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

Kastelein, R.A., L. Helder-Hoek, C. Booth, N, Jennings, and M. Leopold. 2019a. High levels of food intake in harbor porpoises (*Phocoena phocoena*): insight into recovery from disturbance. **Aquatic Mamm.** 45(4):380-388.

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

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

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

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

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

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

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

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

Kastelein, R.A., L. Helder-Hoek, S.A. Cornelisse, A.M. von Benda-Beckmann, F.P.A. Lam, C.A.F. de Jong, and D.R. Ketten. 2020f. Lack of reproducibility of temporary hearing threshold shifts in a harbor porpoise after exposure to repeated airgun sounds. **J. Acoust. Soc. Am.** 148(2):556-565.

Kasuya, T. 1986. Distribution and behavior of Baird's beaked whales off the Pacific coast of Japan. **Sci. Rep. Whales Res. Inst.** 37:61-83.

Kelly, B.P. 1988. Bearded seal, *Erignathus barbatus.* p. 77-94 *In:* J.W. Lentfer (ed.), Selected marine mammals of Alaska/species accounts with research and management recommendations. Mar. Mamm. Comm., Washington, DC. 275 p.

Kelly, B.P., J.L. Bengtson, P. L. Boveng, M.F. Cameron, S.P. Dahle, J.K. Jansen, E.A. Logerwell, J.E. Overland, C.L. Sabine, G.T. Waring, and J.M. Wilder. 2010a . Status review of the ringed seal (*Phoca hispida*). NOAA Technical Memorandum NMFS-AFSC-212. U.S. Department of Commerce, NOAA, National Marine Fisheries Service (NMFS), Alaska Fisheries Science Center. Seattle, WA, p. 250.

Kelly, B.P., O.H. Badajos, M. Kunnasranta, J.R. Moran, M. Martinez-Bakker, D. Wartzok, and P. Boveng. 2010b. Seasonal home ranges and fidelity to breeding sites among ringed seals. **Polar Biol.** 33:1095-1109.

Kertell, K. 1991. Disappearance of the Steller's eider from the Yukon-Kuskokwim delta, Alaska. **Arctic** 44(3):177-187.

Ketten, D.R. 2012. Marine mammal auditory system noise impacts: evidence and incidence. p. 207-212 *In*: A.N. Popper and A. Hawkins (eds.), The effects of noise on aquatic life. Springer, New York, NY. 695 p.

Ketten, D.R., J. O'Malley, P.W.B. Moore, S. Ridgway, and C. Merigo. 2001. Aging, injury, disease, and noise in marine mammal ears. **J. Acoust. Soc. Am.** 110(5, Pt. 2):2721.

King, J.E. 1983. Seals of the world, 2nd ed. Cornell Univ. Press, Ithaca, NY. 240 p.

King, S.L., R.S. Schick, C. Donovan, C.G. Booth, M. Burgman, L. Thomas, and J. Harwood. 2015. An interim framework for assessing the population consequences of disturbance. **Meth. Ecol. Evol. 6**(1):1150-1158.

Klinck, H., S.L. Nieukirk, D.K. Mellinger, K. Klinck, H. Matsumoto, and R.P. Dziak. 2012. Seasonal presence of cetaceans and ambient noise levels in polar waters of the North Atlantic. **J. Acoust. Soc. Am.** 132(3):EL176-EL181.

Kok, A.C.M., J.P. Engelberts, R.A. Kastelein, L. Helder-Hoek, S. Van de Voorde, F. Visser, H. Slabbekoorn. 2017. Spatial avoidance to experimental increase of intermittent and continuous sound in two captive harbour porpoises. **Env. Poll.** 233:1024-1036.

Krieger, K.J. and B.L. Wing. 1984. Hydroacoustic surveys and identification of humpback whale forage in Glacier Bay, Stephens Passage, and Frederick Sound, southeastern Alaska, summer 1983. NOAA Tech. Memo. NMFS F/NWC-66. U.S. Natl. Mar. Fish. Serv., Auke Bay, AK. 60 p. NTIS PB85-183887.

Krieger, K.J. and B.L. Wing. 1986. Hydroacoustic monitoring of prey to determine humpback whale movements. NOAA Tech. Memo. NMFS F/NWC-98. U.S. Natl. Mar. Fish. Serv., Auke Bay, AK. 63 p. NTIS PB86-204054.

Kujawa, S.G. and M.C. Liberman. 2009. Adding insult to injury: cochlear nerve degeneration after “temporary” noise-induced hearing loss. **J. Neurosci.** 29(45):14077-14085.

Kuletz, K.J., M.C. Ferguson, B. Hurley, A.E. Gall, E.A. Labunski, and T.C. Morgan. 2015. Seasonal spatial patterns in seabird and marine mammal distribution in the eastern Chukchi and western Beaufort seas: Identifying biologically important pelagic areas. **Progr. Oceanogr.** 136:175-200.

Kunc, H.P., K.E. McLaughlin, and R. Schmidt. 2016. Aquatic noise pollution: implications for individuals, populations, and ecosystems. **Proc. R. Soc. B** 283:20160839. http://dx.doi.org/doi:10.1098/rspb.2016.0839.

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

Ladich, F. 2019. Ecology of sound communication in fishes. **Fish.** 20(3):552-563.

Lalas, C. and H. McConnell. 2015. Effects of seismic surveys on New Zealand fur seals during daylight hours: do fur seals respond to obstacles rather than airgun noise? **Mar. Mamm. Sci.** http://dx.doi.org/doi: .1111/mms.12293.

Larned, W., R. Stehn, and R. Platte. 2009. Eider breeding population survey, Arctic Coastal Plain, Alaska 2008. USFWS, Migratory Bird Management, Waterfowl Management, Soldatna and Anchorage, AK.

Larsen, T. 1985. Polar bear denning and cub production in Svalbard, Norway. **J. Wildl. Manage.** 49(2):320-326.

Laws, R. 2012. Cetacean hearing-damage zones around a seismic source. p. 473-476 *In*: A.N. Popper and A. Hawkins (eds.), The effects of noise on aquatic life. Springer, New York, NY. 695 p.

Le Prell, C.G. 2012. Noise-induced hearing loss: from animal models to human trials. p. 191-195 *In*: A.N. Popper and A. Hawkins (eds.), The effects of noise on aquatic life. Springer, New York, NY. 695 p.

Leatherwood, S., A.E. Bowles, and R. Reeves. 1986. Aerial surveys of marine mammals in the southeastern Bering Sea. U.S. Department of Commerce, NOAA, OCSEAP Final Report 42:147-490.

LeDuc, R.G., D.W. Weller, J. Hyde, A.M. Burdin, P.E. Rosel, R.L. Brownell Jr, B. Würsig, and A.E. Dizon. 2002. Genetic differences between western and eastern gray whales (*Eschrichtius robustus*). **J. Cetacean Res. Manage.** 4(1):1-5.

Leite, L., D. Campbell, L. Versiani, J. Anchieta, C.C. Nunes, and T. Thiele. 2016. First report of a dead giant squid (*Architeuthis dux*) from an operating seismic vessel. **Mar. Biodivers. Rec.** 9:26.

Lesage, V., A. Omrane, T. Doniol-Valccroze, and A. Mosnier. 2017. Increased proximity of vessels reduces feeding opportunities of blue whales in St. Lawrence Estuary, Canada. **Endang. Species Res.** 32:351–361.

LGL and Greeneridge. 1996. Northstar marine mammal monitoring program, 1995: Baseline surveys and retrospective analyses of marine mammal and ambient noise data from the Central Alaskan Beaufort Sea. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK. 104 p.

Liberman, M.C., M.J. Epstein, S.S. Cleveland, H. Wang, and S.F. Maison. 2016. Toward a differential diagnosis of hidden hearing loss in humans. **PLoS ONE** 11(9):e0162726. doi:10.1371/journal.pone.0162726.

Ljungblad, D.K., S.E. Moore, and D.R. Van Schoik. 1984. Aerial surveys of endangered whales in the Beaufort, eastern Chukchi, and northern Bering Seas, 1983: with a five year review, 1979–1983. NOSC Tech Rep. 955. Rep. from Naval Ocean Systems Center, San Diego, CA, for U.S. Minerals Manage. Serv., Anchorage, AK. 356 p. NTIS AD-A146 373/6.

Logerwell, E., M. Busby, C. Carothers, S. Cotton, J. Duffy-Anderson, E. Farley, P. Goddard, R. Heintz, B. Holladay, J. Horne, S. Johnson, B. Lauth, L. Moulton, D. Neff, B. Norcross, S. Parker-Stetter, J. Seigle, and T. Sformo. 2015. Fish communities across a spectrum of habitats in the western Beaufort Sea and Chukchi Sea. **Prog. Oceanogr.** 136:115-132.

Lowry, L.F., R.R. Nelson, and K.J. Frost. 1987. Observations of killer whales, (*Orcincus orca*) in western Alaska: Sightings, strandings and predation on other marine mammals. **Can. Field-Nat.** 101:6-12.

Lowry, L.F., K.J. Frost, R. Davis, D.P. DeMaster, and R.S. Suydam. 1998. Movements and behavior of satellite-tagged spotted seals (*Phoca largha*) in the Bering and Chukchi Seas. **Polar Biol.** 19(4):221-230.

Løkkeborg, S., E. Ona, A. Vold, and A. Salthaug. 2012. Sounds from seismic air guns: gear- and species-specific effects on catch rates and fish distribution. **Can. J. Fish. Aquat. Sci.** 69(8):1278-1291.

Lucke, K., S.B. Martin, and R. Racca. 2020. Evaluating the predictive strength of underwater noise exposure criteria for marine mammals. **J. Acoust. Soc. Am.** 147(6):3985-3991.

Lucke, K., U. Siebert, P.A. Lepper, and M.-A. Blanchet. 2009. Temporary shift in masked hearing thresholds in a harbor porpoise (*Phocoena phocoena*) after exposure to seismic airgun stimuli. **J. Acoust. Soc. Am.** 125(6):4060-4070.

Luís, A.R., M.N. Couchinho, and M.E. Dos Santos. 2014. Changes in the acoustic behavior of resident bottlenose dolphins near operating vessels. **Mar. Mamm. Sci.** 30(4):1417-1426.

Lurton, X. 2016. Modelling of the sound field radiated by multibeam echosounders for acoustical impact assessment. **Appl. Acoust.** 101:201-216.

Lusseau, D. and L. Bejder. 2007. The long-term consequences of short-term responses to disturbance experience from whalewatching impact assessment. **Int. J. Comp. Psych.** 20(2-3):228-236.

Lyamin, O.I., S.M. Korneva, V.V. Rozhnov, and L.M. Mukhametov. 2016. Cardiorespiratory responses to acoustic noise in belugas. p. 665-672 *In*: A.N. Popper and A. Hawkins (eds.), The effects of noise on aquatic life II. Springer, New York, NY. 1292 p.

MacGillivray, A.O., R. Racca, and Z. Li. 2014. Marine mammal audibility of selected shallow-water survey sources. **J. Acoust. Soc. Am.** 135(1):EL35-EL40.

MacIntyre, K.Q., K.M. Stafford, P.B. Conn, K.L. Laidre, and P.L. Boveng. 2015. The relationship between sea ice concentration and the spatio-temporal distribution of vocalizing bearded seals (*Erignathus barbatus*) in the Bering, Chukchi, and Beaufort Seas from 2008 to 2011. **Prog. Oceanogr.** 136:241-249

Malakoff, D. 2002. Suit ties whale deaths to research cruise. **Science** 298(5594):722-723.

Malme, C.I. and P.R. Miles. 1985. Behavioral responses of marine mammals (gray whales) to seismic discharges. p. 253-280 *In*: G.D. Greene, F.R. Engelhardt, and R.J. Paterson (eds.), Proc. Worksh. Effects Explos. Mar. Envir., Jan. 1985, Halifax, N.S. Tech. Rep. 5. Can. Oil & Gas Lands Admin., Environ. Prot. Br., Ottawa, ON. 398 p.

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

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

MarineTraffic. 2021. Marine Traffic. Accessed in January 2021 at http://www.marinetraffic.com.

Martin, P.D., D.C. Douglas, T. Obritschkewitsch, and S. Torrence. 2015. Distribution and movements of Alaska-breeding Steller's Eiders in the nonbreeding period. **Condor** 117(3):341-353.

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

Martinez-Bakker, M.E., S.K. Sell, B.J. Swanson, B.P. Kelly, and D.A. Tallmon. 2013. Combined genetic and telemetry data reveal high rates of gene flow, migration, and long-distance dispersal potential in Arctic ringed seals (*Pusa hispida*). **PLoS ONE** 8:e77125.

Martins, D.T.L., M.R. Rossi-Santos, and F.J. De Lima Silva. 2016. Effects of anthropogenic noise on the acoustic behaviour of *Sotalia guianensis* (Van Bénéden, 1864) in Pipa, North-eastern Brazil. **J. Mar. Biol. Assoc. U.K.** 2016:1-8.

Mate, B.R., G.K. Krutzikowski, and M.H. Winsor. 2000. Satellite-monitored movements of radio-tagged bowhead whales in the Beaufort and Chukchi seas during the late-summer feeding season and fall migration. **Can. J. Zool.** 78:1168-1181.

Mate, B.R., V.Y. Ilyashenko, A.L. Bradford, V.V. Vetyankin, G.A. Tsidulko, V.V. Rozhnov, and L.M Irvine. 2015. mcCritically endangered western gray whales migrate to the eastern North Pacific. **Biol. Lett.** 11:20150071. doi:10.1098/rsbl.2015.0071.

Matos, F. 2015. Distribution of cetaceans in Vestfjorden, Norway, and possible impacts of seismic surveys. M.Sc. Thesis, University of Nordland, Norway. 45 p.

Matthews, L. 2017. Harbor seal (*Phoca vitulina*) reproductive advertisement behavior and the effects of vessel noise. Ph.D. Thesis, Syracuse University. 139 p.

Matthews, M.N.R., D.S. Ireland, D.G. Zeddies, R.H. Brune, and C.D. Pyć. 2021. A modeling comparison of the potential effects on marine mammals from sounds produced by marine vibroseis and air gun seismic sources. **J. Mar. Sci. Eng.** 9(1). doi:10.3390/jmse9010012.

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

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

McCauley, R.D., J. Fewtrell, A.J. Duncan, C. Jenner, M.-N. Jenner, J.D. Penrose, R.I.T. Prince, A. Adhitya, J. Murdoch, and K. McCabe. 2000. Marine seismic surveys: analysis of airgun signals; and effects of air gun exposure on humpback whales, sea turtles, fishes and squid. Rep. from Centre for Marine Science and Technology, Curtin Univ., Perth, Western Australia, for Australian Petrol. Produc. & Explor. Assoc., Sydney, NSW. 188 p.

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

McDonald, T.L., W.J. Richardson, K.H. Kim, and S.B. Blackwell. 2010. Distribution of calling bowhead whales exposed to underwater sounds from Northstar and distant seismic surveys, 2009. p. 6-1 to 6-38 *In*: W.J. Richardson (ed.), Monitoring of industrial sounds, seals, and bowhead whales near BP's Northstar oil development, Alaskan Beaufort Sea: Comprehensive report for 2005–2009. LGL Rep. P1133-6. Rep. by LGL Alaska Res. Assoc. Inc., Anchorage, AK, Greeneridge Sciences Inc., Santa Barbara, CA, WEST Inc., Cheyenne, WY, and Applied Sociocult. Res., Anchorage, AK, for BP Explor. (Alaska) Inc., Anchorage, AK. 265 p.

McDonald, T.L., W.J. Richardson, K.H. Kim, S.B. Blackwell, and B. Streever. 2011. Distribution of calling bowhead whales exposed to multiple anthropogenic sound sources and comments on analytical methods. p. 199 *In*: Abstr. 19th Bienn. Conf. Biol. Mar. Mamm., 27 Nov.–2 Dec. 2011, Tampa, FL. 344 p.

McGeady, R., B.J. McMahon, and S. Berrow. 2016. The effects of surveying and environmental variables on deep diving odontocete stranding rates along Ireland's coast. Proceedings of Meetings on Acoustics 4ENAL 27(1):040006. doi:10.1121/2.0000281.

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

McLaughlin, F.A., E.C. Carmack, R.W. Macdonald, and J.K.B. Bishop. 1996. Physical and chemical properties across the Atlantic/Pacific water mass front in the southern Canadian Basin**. J. Geophys. Res**. 101, No. C1: 1183-1198. [Abstract]

Meier, S.K., S.B. Yazvenko, S.A. Blokhin, P. Wainwright, M.K. Maminov, Y.M. Yakovlev, and M.W. Newcomer. 2007. Distribution and abundance of western gray whales off northeastern Sakhalin Island, Russia, 2001-2003. **Environ. Monit. Assess.** 134(1-3):107-136.

Melcón, M.L., A.J. Cummins, S.M. Kerosky, L.K. Roche, S.M. Wiggins, and J.A. Hildebrand. 2012. Blue whales respond to anthropogenic noise. **PLoS ONE** 7(2):e32681. doi:10.1371/journal.pone.0032681.

Miller, I. and E. Cripps. 2013. Three dimensional marine seismic survey has no measurable effect on species richness or abundance of a coral reef associated fish community. **Mar. Poll. Bull.** 77(1-2):63-70.

Miller, G.W., R.E. Elliott, W.R. Koski, V.D. Moulton, and W.J. Richardson. 1999. Whales. p. 5-1 to 5-109 *In*: W.J. Richardson (ed.), Marine mammal and acoustical monitoring of Western Geophysical's open-water seismic program in the Alaskan Beaufort Sea, 1998. LGL Rep. TA2230-3. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for Western Geophysical, Houston, TX, and U.S. Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 390 p.

Miller, G.W., R.E. Elliot, T.A. Thomas, V.D. Moulton, and W.R. Koski. 2002. Distribution and numbers of bowhead whales in the eastern Alaskan Beaufort Sea during late summer and autumn, 1979-2000. Chapter 9 *In*: W.J. Richardson and D.H. Thomson (eds), 2002. Bowhead whale feeding in the eastern Alaskan Beaufort Sea: update of scientific and traditional information. OCS Study MMS 2002-012; LGL Rep. TA2196-7. Rep. from LGL Ltd., King City, Ont., for U.S. Minerals Manage. Serv., Anchorage, AK, and Herndon, VA. xliv + 697 p. 2 vol. NTIS PB2004-101568.

Miller, G.W., V.D. Moulton, R.A. Davis, M. Holst, P. Millman, A. MacGillivray, and D. Hannay. 2005. Monitoring seismic effects on marine mammals—southeastern Beaufort Sea, 2001–2002. p. 511-542 *In*: S.L. Armsworthy, P.J. Cranford, and K. Lee (eds.), Offshore oil and gas environmental effects monitoring: approaches and technologies. Battelle Press, Columbus, OH. 631 p.

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

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

Monaco, C., J.M. Ibáñez, F. Carrión, and L.M. Tringali. 2016. Cetacean behavioural responses to noise exposure generated by seismic surveys: how to mitigate better? **Ann. Geophys.** 59(4):S0436. doi:10.4401/ag-7089.

Monnett, C. and S.D. Treacy. 2005. Aerial surveys of endangered whales in the Beaufort Sea, fall 2002–2004. OCS Study MMS 2005-037. Minerals Manage. Serv., Anchorage, AK. xii + 153 p.

Moore, S.E. 2000. Variability in cetacean distribution and habitat selection in the Alaskan Arctic, autumn 1982–91. **Arctic** 53(4):448-460.

Moore, S.E. and R.R. Reeves. 1993. Distribution and movement. p. 313-386 *In*: J.J. Burns, J.J. Montague, and C.J. Cowles (eds.), The bowhead whale. Spec. Publ. 2. Soc. Mar. Mammal., Lawrence, KS. 787 p.

Moore, S.E., J.C. George, K.O. Coyle, and T.J. Weingartner. 1995. Bowhead whales along the Chukotka coast in autumn. **Arctic** 48(2):155-160.

Moore, S.E., D.P. DeMaster, and P.K. Dayton. 2000a. Cetacean habitat selection in the Alaskan Arctic during summer and autumn. **Arctic** 53(4):432-447.

Moore, S.E., J.M. Waite, L.L. Mazzuca, and R.C. Hobbs. 2000b. Mysticete whale abundance and observations of prey associations on the central Bering Sea shelf. **J. Cetac. Res. Manage**. 2(3): 227-234.

Moore, S.E., J.M. Waite, N.A. Friday, and T. Honkalehto. 2002. Cetacean distribution and relative abundance on the central-eastern and the southeastern Bering Sea shelf with reference to oceanographic domains. **Prog. Oceanogr.** 55(1-2):249-261.

Morell, M., A. Brownlow, B. McGovern, S.A. Raverty, R.E. Shadwick, and M. André. 2017. Implementation of a method to visualize noise-induced hearing loss in mass stranded cetaceans. **Sci. Rep.** 7:41848 https://doi.org/10.1038/srep41848.

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

Morris, C.J., D. Cote, B. Martin, and D. Kehler. 2018. Effects of 2D seismic on the snow crab fishery. **Fish. Res.** 197:67-77.

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

Mosher, D.C., J.W. Shimeld, and D.R. Hutchinson. 2009. 2009 Canada Basin seismic reflection and refraction survey, western Arctic Ocean: CCGS *Louis S. St. Laurent* expedition report. Geological Survey of Canada, Ottawa, Ontario.

Moulton, V.D. and M. Holst. 2010. Effects of seismic survey sound on cetaceans in the Northwest Atlantic. Environ. Stud. Res. Funds Rep. No. 182. St. John's, Nfld. 28 p.

Moulton, V.D. and J.W. Lawson. 2002. Seals, 2001. p. 3-1 to 3-46 *In*: W.J. Richardson and J.W. Lawson (eds.), Marine mammal monitoring of WesternGeco's open-water seismic program in the Alaskan Beaufort Sea, 2001. LGL Rep. TA2564-4. Rep. from LGL Ltd., King City, Ont., for WesternGeco LLC, Anchorage, AK; BP Explor. (Alaska) Inc., Anchorage, AK; and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 95 p.

Muir, J.E., L. Ainsworth, R. Joy, R. Racca, Y. Bychkov, G. Gailey, V. Vladimirov, S. Starodymov, and K. Bröker. 2015. Distance from shore as an indicator of disturbance of gray whales during a seismic survey off Sakhalin Island, Russia. **Endang. Species. Res.** 29:161-178.

Muir, J.E., L. Ainsworth, R. Racca, Y. Bychkov, G. Gailey, V. Vladimirov, S. Starodymov, and K. Bröker. 2016. Gray whale densities during a seismic survey off Sakhalin Island, Russia. **Endang. Species Res.** 29(2):211-227.

Mulsow, J., C.E. Schlundt, L. Brandt, and J.J. Finneran. 2015. Equal latency contours for bottlenose dolphins (*Tursiops truncatus*) and California sea lions (*Zalophus californianus*). **J. Acoust. Soc. Am.** 138(5): 2678-2691.

Muto, M.M, V.T. Helker, B.J. Delean, R.P. Angliss, P.L. Boveng, J.M. Breiwick, B.M Brost, M.F. Cameron, P.J. Clapham, S.P. Dahle, M.E. Dahlheim, B.S. Fadely, M.C. Ferguson, L.W. Fritz, R.C. Hobbs, Y.V. Ivashchenko, A.S. Kennedy, J.M. London, S.A. Mizroch, R.R. Ream, E.L. Richmond, K.E.W. Shelden, K.L. Sweeney, R.G. Towell, P.R. Wade, J.M. Waite, and A.N. Zerbini. 2020. Alaska marine mammal stock assessments, 2019. U.S. Dept. of Commerce, NOAA Tech. Memo. NMFS-AFSC-404. 395 p.

Nachtigall, P.E. and A.Y. Supin. 2013. A false killer whale reduces its hearing sensitivity when a loud sound is preceded by a warning. **J. Exp. Biol.** 216:3062-3070.

Nachtigall, P.E. and A.Y. Supin. 2014. Conditioned hearing sensitivity reduction in the bottlenose dolphin (*Tursiops truncatus*). **J. Exp. Biol.** 217(15): 2806-2813.

Nachtigall, P.E. and A.Y. Supin. 2015. Conditioned frequency-dependent hearing sensitivity reduction in the bottlenose dolphin (*Tursiops truncatus*). **J. Exp. Biol.** 218(7): 999-1005.

Nachtigall, P.E. and A.Y. Supin. 2016. Hearing sensation changes when a warning predict a loud sound in the false killer whale (*Pseurorca crassidens*). p. 743-746 *In*: A.N. Popper and A. Hawkins (eds.), The effects of noise on aquatic life II. Springer, New York, NY. 1292 p.

Nachtigall, P.E., A.Y. Supin, A.F. Pacini, and R.A. Kastelein. 2018. Four odontocete species change hearing levels when warned of impending loud sound. **Integr. Zool.** 13(2):160-165.

National Academies of Sciences, Engineering, and Medicine. 2017. Approaches to understanding the cumulative effects of stressors on marine mammals. The National Academies Press. Washington, DC. 134 p.

Nerini, M. 1984. A review of gray whale feeding ecology. p. 423-450 *In*: Jones, M.L., S.I. Swartz, and S. Leatherwood (eds.), The gray whale, *Eschrichtius robustus*. Academic Press, Inc. Orlando, FL. 600 p.

New, L.F., J. Harwood, L. Thomas, C. Donovan, J.S. Clark, G. Hastie, P.M. Thompson, B. Cheney, L. Scott-Hayward, and D. Lusseau. 2013a. Modelling the biological significance of behavioural change in coastal bottlenose dolphins in response to disturbance. **Funct. Ecol.** 27(2):314-322.

New, L.F., D. Moretti, S.K. Hooker, D.P. Costa, and S.E. Simmons. 2013b. Using energetic models to investigate the survival and reproduction of beaked whales (family Ziphiidae). **PLoS ONE** 8(7):e68725.

Nieukirk, S.L., D.K. Mellinger, S.E. Moore, K. Klinck, R.P. Dziak, and J. Goslin. 2012. Sounds from airguns and fin whales recorded in the mid-Atlantic Ocean, 1999–2009. **J. Acoust. Soc. Am.** 131(2):1102-1112.

NMFS (National Marine Fisheries Service). 2001. Small takes of marine mammals incidental to specified activities: oil and gas exploration drilling activities in the Beaufort Sea/Notice of issuance of an incidental harassment authorization. **Fed. Reg.** 66(26, 7 Feb.):9291-9298.

NMFS. 2014. Designation of critical habitat for the Arctic ringed seal. Proposed Rule. **Fed. Reg**. 79(236, 9 Dec.):73010-73025.

NMFS. 2016a. Technical guidance for assessing the effects of anthropogenic sound on marine mammal hearing: underwater acoustic thresholds for onset of permanent and temporary threshold shifts. U.S. Depart. Commerce, National Oceanic and Atmospheric Administration. 178 p.

NMFS. 2016b. Endangered and threatened species; identification of 14 distinct population segments of the humpback whale (*Megaptera novaeangliae*) and revision of species-wide listing. Final Rule. **Fed. Reg.** 81(174, 8 Sept.):62260-62320.

NMFS. 2016c. Effects of oil and gas activities in the Arctic Ocean: supplemental draft environmental impact statement. U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Office of Protected Resources. Available at http://www.nmfs.noaa.gov/pr//eis/arctic.htm.

NMFS. 2018. 2018 revision to: technical guidance for assessing the effects of anthropogenic sound on marine mammal hearing (version 2.0). Underwater thresholds for onset of permanent and temporary threshold shifts. Office of Protected Resources Nat. Mar. Fish. Serv., Silver Spring, MD. 167 p.

NMFS. 2019a. Endangered and threatened wildlife and plants: proposed rule to designate critical habitat for the Central America, Mexico, and Western North Pacific Distinct Population Segments of Humpback Whales. **Fed. Reg.** 84(196, 9 Oct.):54354-54391.

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

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

NMFS. 2019d. Biological Opinion: Office of Naval Research (ONR) Arctic Research Activities 2018-2021 and Associated proposed Issuance of an Incidental Harassment Authorization in the Beaufor Sea, Alaska. NMFS, office of Protected Resources, Permis and Conservation Division. Accessed January 2021 at https://www.fisheries.noaa.gov/resource/document/biological-opinion-office-naval-research-arctic-research-activities-2018-2021-and

NMFS. 2021a. Endangered and threatened species; designation of critical habitat for the Arctic subspecies of the ringed seal. **Fed. Reg.** 86(5, 8 January):1452-1474.

NMFS. 2021b. Endangered and threatened species; designation of critical habitat for the Beringia distinct population segment of the bearded seal. **Fed. Reg.** 86(5, 8 January):1433-1452.

NOAA (National Oceanic and Atmospheric Administration). 2017. Glossary. Accessed January 2021 at https://marineprotectedareas.noaa.gov/glossary_pr.html

NOAA. 2020. Essential Fish Habitat Mapper. Accessed January 2021 at https://www.fisheries.noaa.gov/resource/map/essential-fish-habitat-mapper

NOAA. 2021a. Species Directory. Accessed January 2021 at https://www.fisheries.noaa.gov/species-directory/threatened-endangered

NOAA. 2021b. 2019-2021 Gray Whale Unusual Mortality Event along the West Coast and Alaska. Accessed January 2021 at https://www.fisheries.noaa.gov/national/marine-life-distress/2019-2021-gray-whale-unusual-mortality-event-along-west-coast-and

NOAA. 2021c. 2018-2021 Ice Seal Unusual Mortality Event in Alaska. Accessed January 2021 at https://www.fisheries.noaa.gov/alaska/marine-life-distress/2018-2021-ice-seal-unusual-mortality-event-alaska.

NOAA. 2021d. Alaska Essential Fish Habitat (EFH) Mapper. Accessed January 2021 at https://www.fisheries.noaa.gov/resource/map/alaska-essential-fish-habitat-efh-mapper

NOAA. 2021e. Active and Closed Unusual Mortality Events. Accessed January 2021 at https://www.fisheries.noaa.gov/national/marine-life-distress/active-and-closed-unusual-mortality-events.

NOAA. 2021f. IB 20-80: NOAA Fisheries Reports Take of a Second Short-tailed Albatross in the BSAI. Accessed February 2021 at https://www.fisheries.noaa.gov/bulletin/ib-20-80-noaa-fisheries-reports-take-second-short-tailed-albatross-bsai.

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

Nowacek, D.P., A.I. Vedenev, B.L. Southall, and R. Racca. 2012. Development and implementation of criteria for exposure of western gray whales to oil and gas industry noise. p. 523-528 *In*: A.N. Popper and A. Hawkins (eds.), The effects of noise on aquatic life. Springer, New York, NY. 695 p.

Nowacek, D.P., K. Bröker, G. Donovan, G. Gailey, R. Racca, R.R. Reeves, A.I. Vedenev, D.W. Weller, and B.L. Southall. 2013a. Responsible practices for minimizing and monitoring environmental impacts of marine seismic surveys with an emphasis on marine mammals. **Aquatic Mamm.** 39(4):356-377.

Nowacek, D.P., K. Bröker, G. Donovan, G. Gailey, R. Racca, R.R. Reeves, A.I. Vedenev, D.W. Weller, and B.L. Southall. 2013b. Environmental impacts of marine seismic surveys with an emphasis on marine mammals. **Aquatic Mamm.** 39(4):356-377.

Nowacek, D.P., C.W. Clark, P. Mann, P.J.O. Miller, H.C. Rosenbaum, J.S. Golden, M. Jasny, J. Kraska, and B.L. Southall. 2015. Marine seismic surveys and ocean noise: time for coordinated and prudent planning. **Front. Ecol. Environ.** 13(7):378-386.

Nowacek, D.P., F. Christiansen, L. Bejder, J.A. Goldbogen, and A.S. Friedlaender. 2016. Studying cetacean behaviour: new technological approaches and conservation applications. **Animal Behav.** http://dx.doi.org/:10.1016/j.anbehav.2016.07.019.

NPFMC (North Pacific Fishery Management Council). 2009. Fishery Management Plan for fish resources of the Arctic Management Area. North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK, 99501. 158 pp + Amendement 2. Accessed at https://media.fisheries.noaa.gov/dam-migration/arctic-2-fmp-text-with-app-akr.pdf

NPFMC. 2018. Fishery Management Plan for the salmon fisheries in the EEZ off Alaska. North Pacific Fishery Management Council, 605 W. 4th Ave., Suite 306, Anchorage, AK, 99501. 152 p + Amendment 13 Accessed January 2021 at https://media.fisheries.noaa.gov/dam-migration/salmon-13-amd-fmp-text-efh-omnibus-with-app-akr.pdf.

NPFMC. 2021. Arctic Fishery Management. Accessed January 2021 at https://www.npfmc.org/arctic-fishery-management/.

NRC (National Research Council). 2005. Marine mammal populations and ocean noise/Determining when noise causes biologically significant effects. U.S. Nat. Res. Counc., Ocean Studies Board, Committee on characterizing biologically significant marine mammal behavior (Wartzok, D.W., J. Altmann, W. Au, K. Ralls, A. Starfield, and P.L. Tyack). Nat. Acad. Press, Washington, DC. 126 p.

NSF (National Science Foundation). 2012. Record of Decision for marine seismic research funded by the National Science Foundation. June 2012. 41 p.

NSF and USGS (NSF and U.S. Geological Survey). 2011. Final programmatic environmental impact statement/Overseas environmental impact statement for marine seismic research funded by the National Science Foundation or conducted by the U.S. Geological Survey.

Oakley, J.A., A.T. Williams, and T. Thomas. 2017. Reactions of harbour porpoise (*Phocoena phocoena*) to vessel traffic in the coastal waters of South Wales, UK. **Ocean & Coastal Manage.** 138:158–169.

OBIS (Ocean Biodiversity Information System). 2012. Accessed January 2021 at https://mapper.obis.org/

O'Brien, J.M., S. Beck, S.D. Berrow, M. André, M. van der Schaar, I. O'Connor, and E.P. McKeown. 2016. The use of deep water berths and the effect of noise on bottlenose dolphins in the Shannon Estuary cSAC. p. 775-783 *In*: The effects of noise on aquatic life II, Springer, New York, NY. 1292 p.

O'Corry-Crowe, G.M., R.S. Suydam, A. Rosenberg, K.J. Frost, and A.E. Dizon. 1997. Phylogeography, population structure and dispersal patterns of the beluga whale *Delphinapterus leucas* in the western Nearctic revealed by mitochondrial DNA. **Molec. Ecol.** 6(10):955-970.

O'Corry-Crowe, G., A.R. Mahoney, R. Suydam, L. Quakenbush, A. Whiting, L. Lowry, and L. Harwood. 2016. Genetic profiling links changing sea-ice to shifting beluga whale migration patterns. **Biol. Lett.** 12(11): 20160404.

Ohsumi, S. and S. Wada. 1974. Status of whale stocks in the North Pacific, 1972. **Rep. Int. Whal. Comm.** 25:114-126.

Orben, R.A., A.J.O'Connor, R.M. Suryan, K. Ozaki, F. Sato, and T. Deguchi. 2018. Ontogenetic changes in at-sea distributions of immature short-tailed albatrosses *Phoebastria albatrus*. **Endang. Sp. Res.** 35:23-37.

Papale, E., M. Gamba, M. Perez-Gil, V.M. Martin, and C. Giacoma. 2015. Dolphins adjust species-specific frequency parameters to compensate for increasing background noise. **PLoS ONE** 10(4):e0121711. http://dx.doi.org/doi:10.1371/journal.pone.0121711.

Parks, S.E., M. Johnson, D. Nowacek, and P.L. Tyack. 2011. Individual right whales call louder in increased environmental noise. **Biol. Lett.** 7(1):33-35.

Parks, S.E., M.P. Johnson, D.P. Nowacek, and P.L. Tyack. 2012. Changes in vocal behaviour of North Atlantic right whales in increased noise. p. 317-320 *In*: A.N. Popper and A. Hawkins (eds.), The effects of noise on aquatic life. Springer, New York, NY. 695 p.

Parks, S.E., K. Groch, P. Flores, R. Sousa-Lima, and I.R. Urazghildiiev. 2016a. Humans, fish, and whales: how right whales modify calling behavior in response to shifting background noise conditions. p. 809-813 *In*: A.N. Popper and A. Hawkins (eds.), The effects of noise on aquatic life II. Springer, New York, NY. 1292 p.

Parks, S.E., D.A. Cusano, A. Bocconcelli, and A.S. Friedlaender. 2016b. Noise impacts on social sound production by foraging humpback whales. Abstr. 4th Int. Conf. Effects of Noise on Aquatic Life, July 2016, Dublin, Ireland.

Parry, G.D., S. Heislers, G.F. Werner, M.D. Asplin, and A. Gason. 2002. Assessment of environmental effects of seismic testing on scallop fisheries in Bass Strait. Marine and Freshwater Resources Institute. Report No. 50.

Paxton, A.B., J.C. Taylor, D.P. Nowacek, J. Dale, E. Cole, C.M. Voss, and C.H. Peterson. 2017. Seismic survey noise disrupted fish use of a temperate reef. **Mar. Policy** 78:68-73.

Payne, R. 1978. Behavior and vocalizations of humpback whales (*Megaptera* sp.). *In*: K.S. Norris and R.R. Reeves (eds.), Report on a workshop on problems related to humpback whales (*Megaptera novaeangliae*) in Hawaii. MCC-77/03. Rep. from Sea Life Inc., Makapuu Pt., HI, for U.S. Mar. Mamm. Comm., Washington, DC.

Payne, J.F., C.D. Andrews, J. Hanlon, and J. Lawson. 2015. Effects of seismic air-gun sounds on lobster (*Homarus americanus*): pilot laboratory studies with (i) a recorded track from a seismic survey and (ii) air-gun pulse exposures over 5 days. ESRF-NRC 197. 38 p.

Pearson, W., J. Skalski, S. Sulkin, and C. Malme. 1994. Effects of seismic energy releases on the survival and development of zoeal larvae of Dungeness crab (*Cancer magister*). **Mar. Env. Res**. 38:93-113.

Peña, H., N.O. Handegard, and E. Ona. 2013. Feeding herring schools do not react to seismic air gun surveys. **ICES J. Mar. Sci.** 70(6):1174-1180. http://dx.doi.org/doi:10.1093/icesjms/fst079.

Peng, C., X. Zhao, and G. Liu. 2015. Noise in the sea and its impacts on marine organisms. **Int. J. Environ. Res. Public Health** (12):12304-12323. http://dx.doi.org/doi:10.3390/ijerph121012304.

Perrin, W.F., S.D. Mallette, and R.L. Brownell Jr. 2018. Minke whales *Balaenoptera acutorostrata* and *B. bonaerensis*. p. 608-613 *In:* B. Würsig, J.G.M. Thewissen, and K.M. Kovacs (eds.), Encyclopedia of Marine Mammals, 3rd ed. Academic Press/Elsevier, San Diego, CA. 1157 p.

Petersen, M.R., J.B. Grand, and C.P. Dau. 2000. Spectacled eider (*Somateria fischeri*). *In*: A. Poole and F. Gill (eds.), The Birds of North America, No. 547. The Birds of North America, Inc., Philadelphia, PA.

Piatt, J., J. Wetzel, K. Bell, A. Degange, G. Balogh, G. Drew, T. Geernaert, C. Ladd, and G. Byrd. 2006. Predictable hotspots and foraging habitat of the endangered short-tailed albatross (*Phoebastria albatrus*) in the North Pacific: implications for conservation. **Deep Sea Res. Part II** 53:387-398.

Piatt, J.F., K.J. Kuletz, A.E., Burger, S.A. Hatch, V.L Friesen, T.P. Birt, M.L. Arimitsu, G.S. Drew, A.M.A. Harding, and K.S. Bixler. 2007. Status review of the marbled murrelet (*Brachyramphus marmoratus*) in Alaska and British Columbia: U.S. Geological Survey Open-File Report 2006-1387.

Pichegru, L., R. Nyengera, A.M. McInnes, and P. Pistorius. 2107. Avoidance of seismic survey activities by penguins. **Sci. Rep.** 7:16305. doi:10.1038/s41598-017-16569-x.

Pierson, M.O., J.P. Wagner, V. Langford, P. Birnie, and M.L. Tasker. 1998. Protection from, and mitigation of, the potential effects of seismic exploration on marine mammals. Chapter 7 *In*: M.L. Tasker and C. Weir (eds.), Proc. Seismic Mar. Mamm. Worksh., London, UK., 23–25 June 1998.

Pine, M.K., K. Nikolich, B. Martin, C. Morris, and F. Juanes. 2020. Assessing auditory masking for management of underwater athropogenic noise. **J. Acoust. Soc. Am.** 147(5):3408-3417.

Pirotta, E., R. Milor, N. Quick, D. Moretti, N. Di Marzio, P. Tyack, I. Boyd, and G. Hastie. 2012. Vessel noise affects beaked whale behavior: results of a dedicated acoustic response study. **PLoS ONE** 7(8):e42535. doi:10.1371/journal.pone.0042535.

Pirotta, E., K.L. Brookdes, I.M. Graham, and P.M. Thompson. 2014. Variation in harbour porpoise activity in response to seismic survey noise. **Biol. Lett.** 10:20131090. doi:10.1098/rsbl.2013.1090.

Pirotta, E., N.D. Merchant, P.M. Thompson, T.R. Barton, and D. Lusseau. 2015. Quantifying the effect of boat disturbance on bottlenose dolphin foraging activity. **Biol. Conserv.** 181:82-98.

Pirotta, E., M. Mangel, D.P. Costa, B. Mate, J.A. Goldbogen, D.M. Palacios, L.A. Hückstädt, E.A. McHuron, L. Schwartz, and L. New. 2018. A dynamic state model of migratory behavior and physiology to assess the consequence of environmental variation and anthropogenic disturbance on marine vertebrates. **Am. Nat.** 191(2):E000-E000. doi:10.5061/dryad.md416.

Popov, V.V., A.Y. Supin, D. Wang, K. Wang, L. Dong, and S. Wang. 2011. Noise-induced temporary threshold shift and recovery in Yangtze finless porpoises *Neophocaena phocaenoides asiaeorientalis*. **J. Acoust. Soc. Am.** 130(1):574-584.

Popov, V.V., A.Y. Supin, V.V. Rozhnov, D.I. Nechaev, E.V. Sysuyeva, V.O. Klishin, M.G. Pletenko, and M.B. Tarakanov. 2013. Hearing threshold shifts and recovery after noise exposure in beluga whales, *Delphinapterus leucas*. **J. Exp. Biol.** 216:1587-1596.

Popov, V.V., D.I. Nechaev, E.V. Sysueva, V.V. Rozhnov, and A.Y. Supin. 2015. Spectrum pattern resolution after noise exposure in a beluga whale: evoked potential study. **J. Acoust. Soc. Am.** 138(1):377-388.

Popov, V., A. Supin, D. Nechaev, E.V. Sysueva, and V. Rozhnov. 2016. Temporary threshold shifts in naïve and experienced belugas: Can dampening of the effects of fatiguing sounds be learned? p. 853-859 *In*: A.N. Popper and A. Hawkins (eds.), The effects of noise on aquatic life II. Springer, New York, NY. 1292 p.

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

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

Popper, A.N. and M.C. Hastings. 2009a. The effects of human-generated sound on fish. **Integr. Zool.** 4:43-52.

Popper, A.N. and M.C. Hastings. 2009b. The effects of anthropogenic sources of sound on fishes. **J. Fish Biol.** 75:455-489.

Popper, A.N. and A.D. Hawkins. 2018. The importance of particle motion to fishes and invertebrates. **J. Acoust. Soc. Am.** 143(1):470-488.

Popper, A.N. and A.D. Hawkins. 2019. An overview of fish bioacoustics and the impacts of anthropogenic sounds on fishes. **J. Fish Biol.** 94: 692-713. https://doi.org/10.1111/jfb.13948

Popper, A.N., A.D. Hawkins, R.R. Fay, D.A. Mann, S, Bartol, T.J. Carlson, S. Coombs, W.T. Ellison, R.L. Gentry, M.B. Halvorsen, S. Løkkeborg, P.H. Rogers, B.L. Southall, D.G. Zeddies, and W.N. Tavolga. 2014. Sound exposure guidelines for fishes and sea turtles. A technical report prepared by ANSI-Accredited Standards Committee S3/SC1 and registered with ANSI. Springer Briefs in Oceanography. ASA Press—ASA S3/SC1.4 TR-2014. 75 p.

Popper, A.N., T.J. Carlson, J.A. Gross, A.D. Hawkins, D.G. Zeddies, L. Powell, and J. Young. 2016. Effects of seismic air guns on pallid sturgeon and paddlefish. p. 871-878 *In*: A.N. Popper and A. Hawkins (eds.), The effects of noise on aquatic life II. Springer, New York, NY. 1292 p.

Popper, A.N., A.D. Hawkins, O. Sand, and J.A. Sisneros. 2019a. Examining the hearing abilities of fishes. **J. Acoust. Soc. Am.** 146. doi:10.1121/1.5120185.

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

Popper, A.N., A.D. Hawkins, and F. Thomsen. 2020a. Taking the animals' perspective regarding anthropogenic underwater sound. **Trends Ecol. Evol.** 2692:1–8.

Popper, A.N., A.D. Hawkins, O. Sand, and J.A. Sisneros. 2020b. Examining the hearing abilities of fishes. **J. Acoust. Soc. Am.** 146(2):948-955.

Przeslawski, R., B. Bruce, A. Carroll, J. Anderson, R. Bradford, A. Durrant, M. Edmunds, S. Foster, Z. Huang, L. Hurt, M. Lansdell, K. Lee, C. Lees, P. Nichols, and S. Williams. 2016. Marine seismic survey impacts on fish and invertebrates: final report for the Gippsland Marine Environmental Monitoring Project. Record 2016/35. Geoscience Australia, Canberra.

Przeslawski, R., Z. Huang, J. Anderson, A.G. Carroll, M. Edmunds, L. Hurt, and S. Williams. 2018. Multiple field-based methods to assess the potential impacts of seismic surveys on scallops. **Mar. Poll. Bull.** 129:750-761. doi:10.1016/j. marpolbul.2017.10.066.

Putland, R.L., N.D. Merchant, A. Farcas, and C.A. Radford. 2017. Vessel noise cuts down communication space for vocalizing fish and marine mammals. **Glob. Change Biol.** doi:10.1111/gcb.13996.

Quakenbush, L.T. 2007. Preliminary satellite telemetry results for Bering-Chukchi-Beaufort bowhead whales. Working paper SC/59/BRG12. Int. Whal. Comm., Cambridge, U.K.

Quakenbush, L.T., J.J. Citta, J.C. George, R.J. Small, and M.P. Heide-Jørgensen. 2010a. Fall and winter movements of bowhead whales (*Balaena mysticetus*) in the Chukchi Sea and within a potential petroleum development area. **Arctic** 63:289-307.

Quakenbush, L.T., R.J. Small, and J.J. Citta. 2010b. Satellite tracking of western Arctic bowhead whale. OCS Study BOEMRE 2010-033. Minerals Manage. Serv., Anchorage, AK. 118 p.

Quakenbush, L., J. Citta, J.C. George, M.P. Heide-Jørgensen, H. Brower, L. Harwood, B. Adams, C. Pokiak, J. Pokiak, and E. Lea. 2018. Bering-Chukchi-Beaufort stock of bowhead whales: 2006-2017 satellite telemetry results with some observations on stock sub-structure. Unpubl. doc. submitted to Int. Whal. Comm. Scientific Committee (SC/67B/AWMP/04). 25 p.

Quick, N., L. Scott-Hayward, D. Sadykova, D. Nowacek, and A.J. Read. 2017. Effects of a scientific echo sounder on the behavior of short-finned pilot whales (*Globicephala macrorhynchus*). **Can. J. Fish. Aquat. Sci**. 74:716–726.

Radford, A.N., E. Kerridge, and S.D. Simpson. 2014. Acoustic communication in a noisy world: Can fish compete with anthropogenic noise? **Behav. Ecol.** 25(5):1022-1030.

Radford A.N., L. Lèbre, G. Lecaillon, S.L. Nedelec, and S.D. Simpson. 2016. Repeated exposure reduces the response to impulsive noise in European seabass. **Glob. Chang. Biol.** 22(10):3349–3360.

Ray, C.E. 1971. Polar bear and mammoth on the Pribilof Islands. **Arctic** 24(1):9-19.

Redfern, J.V., M.F. McKenna, T.J. Moore, J. Calambokidis, M.L. Deangelis, E.A. Becker, J. Barlow, K.A. Forney, P.C. Fiedler, and S.J. Chivers. 2013. Assessing the risk of ships striking large whales in marine spatial planning. **Conserv. Biol.** 27(2):292-302.

Reeves, R.R., B.S. Stewart, P.J. Clapham, and J.A. Powell. 2002. Guide to marine mammals of the world. Chanticleer Press, New York, NY. 525 p.

Reeves, R.R., B.D. Smith, E. Crespo, G. Notarbartolo di Sciara, and the Cetacean Specialist Group. 2003. Dolphins, whales, and porpoises: 2003–2010 conservation action plan for the world's cetaceans. IUCN Species Survival Commission, Gland, Switzerland.

Reichmuth, C., A. Ghoul, A. Rouse, J. Sills, and B. Southall. 2016. Low-frequency temporary threshold shift not measured in spotted or ringed seals exposed to single airgun impulses. **J. Acoust. Soc. Am.** 140(4):2646-2658.

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

Rice, D.W. and A.A. Wolman. 1971. The life history and ecology of the gray whale (*Eschrichtius robustus*). Soc. Mar. Mammal., Spec. Publ. 3, Allen Press, Lawrence, KS.

Rice, A.N., J.T. Tielens, B.J. Estabrook, C.A. Muirhead, A. Rahaman, M. Guerra, and C.W. Clark. 2014. Variation of ocean acoustic environments along the western North Atlantic coast: a case study in context of the right whale migration route. **Ecol. Inform.** 21:89-99.

Richard, P.R., A.R. Martin, and J.R. Orr. 1997. Study of summer and fall movements and dive behaviour of Beaufort Sea belugas, using satellite telemetry: 1992–1995. ESRF Rep. 134. Environ. Stud. Res. Funds, Calgary, Alb. 38 p.

Richard, P.R., A.R. Martin, and J.R. Orr. 2001. Summer and autumn movements of belugas of the eastern Beaufort Sea stock. **Arctic** 54(3):223-236.

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

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

Richardson, W.J., G.W. Miller, and C.R. Greene, Jr. 1999. Displacement of migrating bowhead whales by sounds from seismic surveys in shallow waters of the Beaufort Sea. **J. Acoust. Soc. Am.** 106(4, Pt. 2):2281 (Abstr.).

Risch, D., P.J. Corkeron, W.T. Ellison, and S.M. Van Parijs. 2012. Changes in humpback whale song occurrence in response to an acoustic source 200 km away. **PLoS One** 7:e29741. doi:10.1371/.pone.0029741.

Risch, D., P.J. Corkeron, W.T. Ellison, and S.M. Van Parijs. 2014. Formal comment to Gong et al.: Ecosystem scale acoustic sensing reveals humpback whale behavior synchronous with herring spawning processes and re-evaluation finds no effect of sonar on humpback song occurrence in the Gulf of Maine in fall 2006. **PLoS One** 9(10):e109225. doi:10.1371/journal.pone.0109225.

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

Roberts, L. and M.E. Laidre. 2019. Finding a home in the noise: cross-modal impact of anthropogenic vibration on animal search behaviour. **Biol. Open** 8:bio041988.

Robertson, F.C., W.R. Koski, T.A. Thomas, W.J. Richardson, B. Würsig, and A.W. Trites. 2013. Seismic operations have variable effects on dive-cycle behavior of bowhead whales in the Beaufort Sea. **Endang. Species Res.** 21:143-160.

Rolland, R.M., S.E. Parks, K.E. Hunt, M. Castellote, P.J. Corkeron, D.P. Nowacek, S.K. Water, and S.D. Kraus. 2012. Evidence that ship noise increases stress in right whales. **Proc. R. Soc. B** 279:2363-2368.

Rosel, P.E., A.E. Dizon, and M.G. Haygood. 1995. Variability of the mitochondrial control region in populations of the harbour porpoise, *Phocoena*, on inter-oceanic and regional scales. **Can. J. Fish. Aqu. Sci.** 52(6):1210-1219.

RPS. 2012. Protected Species Mitigation and Monitoring Report. Coakley Marine Geophysical Survey in the Arctic Ocean, 8 Septemer 2011-9 October 2011, R/V Marcus G. Langseth. Report from RPS for Lamont-Doherty Earth Observatory, Palisades, NY, and NMFS, Silver Spring, MD.

RPS. 2014. Final environmental assessment for seismic reflection scientific research surveys during 2014 and 2015 in support of mapping the U.S. Atlantic seaboard extended continental margin and investigating tsunami hazards. Rep. from RPS for United States Geological Survey, August 2014. Accessed in March 2017 at http://www.nsf.gov/geo/oce/envcomp/usgssurveyfinalea2014.pdf.

Rugh, D.J. and M.A. Fraker. 1981. Gray whale (*Eschrichtius robustus*) sightings in eastern Beaufort Sea. **Arctic** 34(2):186-187.

Rugh, D.J., K.E.W. Shelden, and D.E. Withrow. 1997. Spotted seals, *Phoca largha*, in Alaska. **Mar. Fish. Rev.** 59(1):1-18.

Sairanen, E.E. 2014. Weather and ship induced sounds and the effect of shipping on harbor porpoise (*Phocoena phocoena*) activity. M.Sc. Thesis, University of Helsinki. 67 p.

Salden, D.R. 1993. Effects of research boat approaches on humpback whale behavior off Maui, Hawaii, 1989−1993. p. 94 In: Abstr. 10th Bienn. Conf. Biol. Mar. Mamm., Galveston, TX, Nov. 1993. 130 p.

Sarnocińska J., J. Teilmann J,D. Balle, F.M. van Beest, M. Delefosse, and J. Tougaard. 2020. Harbor porpoise (*Phocoena phocoena*) reaction to a 3D seismic airgun survey in the North Sea. **Front. Mar. Sci.** 6:824. doi:10.3389/fmars.2019.00824

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

Savarese, D.M., C.R. Reiser, D.S. Ireland, and R. Rodrigues. 2010. Beaufort Sea vessel-based monitoring program. Chapter 6 *In*: D.W. Funk, D.S. Ireland, R. Rodrigues, and W.R. Koski (eds.), 2009. Joint monitoring program in the Chukchi and Beaufort seas, open water seasons, 2006–2008. LGL Alaska Report P1050-2. Rep. from LGL Alaska Research Associates, Inc., LGL Ltd., Greeneridge Sciences, Inc., and JASCO Research, Ltd., for Shell Offshore, Inc. and other Industry contributors, National Marine Fisheries Service, and U.S. Fish and Wildlife Service. 506 p. + app.

Schick, R.S., J.J. Roberts, and P.N. Halpin. 2017. Marine Species Density Models for the Arctic Environmental Impact Statement (EIS) Study Area. Final Report. Prepared for U.S. Fleet Forces Command. Submitted to Naval Facilities Engineering Command Atlantic, Norfolk, Virginia, under Contract No. N62470-15-D-8006, Task Order TO11, issued to HDR, San Diego, California. November 2017.

Schlundt, C.E., J.J. Finneran, D.A. Carder, and S.H. Ridgway. 2016. Temporary shift in masking hearing thresholds of bottlenose dolphins, *Tursiops truncatus*, and white whales, *Delphinapterus leucas*, after exposure to intense tones. p. 987-991 *In*: A.N. Popper and A. Hawkins (eds.), The effects of noise on aquatic life II. Springer, New York, NY. 1292 p.

Scholik-Schlomer, A. 2015. Where the decibels hit the water: perspectives on the application of science to real-world underwater noise and marine protected species issues. **Acoustics Today** 11(3):36-44.

Sciacca, V., S. Viola, S. Pulvirenti, G. Riccobene, F. Caruso, E. De Domenico, and G. Pavan. 2016. Shipping noise and seismic airgun surveys in the Ionian Sea: potential impact on Mediterranean fin whale. Proceedings of Meetings on Acoustics 4ENAL 27(1):040010. doi:10.1121/2.0000311.

Sea Around Us Project. 2021. Catches by taxon in waters of USA (Alaska, Arctic). University of British Columbia Fisheries Centre. Accessed January 2021 at http://www.seaaroundus.org/data/#/eez/958?chart=catch-chart&dimension=taxon&measure=tonnage&limit=10.

Sease, J.L. and D.G. Chapman. 1988. Pacific walrus (*Odobenus rosmarus divergens*). p. 17-38 *In* J.W. Lentfer (eds) Selected marine mammals of Alaska: species accounts with research and management recommendations. Mar. Mamm. Comm., Washington, D.C. NTIS PB88-178462.

Sekiguchi, K., T. Uyama, and K. Yamshiro. 2008. Cetacean sighting survey during T/S *Oshoro Maru* Bering and Chukchi Sea cruise, 1 July–28 August 2007. Unpublished cruise report. Available at National Marine Mammal Laboratory, Alaska Fish. Sci. Cent., 7600 Sand Point Way NE, Seattle, WA 98115.

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

Sexson, M.G., J.M. Pearce, and M.R. Petersen. 2014. Spatiotemporal distribution and migratory patterns of Spectacled Eiders. BOEM 2014-665. Bureau of Ocean Energy Management, Alaska Outer Continental Shelf Region, Anchorage, Alaska.

Sexson, M.G., M.R. Petersen, G.A. Breed, and A.N. Powell. 2016. Shifts in the distribution of molting Spectacled Eiders (*Somateria fischeri*) indicate ecosystem change in the Arctic. **Condor** 118(3):463-476.

Shaughnessy, P.D. and F.H. Fay. 1977. A review of the taxonomy and nomenclature of North Pacific harbor seals. **J. Zool. (Lond.)** 182:385-419.

Sidorovskaia, N., B. Ma, A.S. Ackleh, C. Tiemann, G.E. Ioup, and J.W. Ioup. 2014. Acoustic studies of the effects of environmental stresses on marine mammals in large ocean basins. p. 1155 *In*: AGU Fall Meeting Abstracts, Vol. 1.

Sierra-Flores R., T. Atack, H. Migaud, and A. Davie. 2015. Stress response to anthropogenic noise in Atlantic cod *Gadus morhua* L. **Aquacult. Eng.** 67:67-76.

Sills, J.M., B.L. Southall, and C. Reichmuth. 2017. The influence of temporally varying noise from seismic air guns on the detection of underwater sounds by seals. **J. Acoust. Soc. Am.** 141(2):996-1008.

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

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

Simmonds, M.P., S.J. Dolman, M. Jasny, E.C.M. Parsons, L. Weilgart, A.J. Wright, and R. Leaper. 2014. Marine noise pollution – Increasing recognition but need for more practical action. **J. Ocean Tech.** 9:71-90.

Slabbekoorn, H., J. Dalen, D. de Haan, H.V. Winter, C. Radford, M.A. Ainslie, K.D. Heaney, T. van Kooten, L. Thomas, and J. Harwood. 2019. Population-level consequences of seismic surveys on fishes: An interdisciplinary challenge. **Fish and Fisheries**. doi:10.1111/faf.12367.

Smith, T.G. and I. Stirling. 1975. The breeding habitat of the ringed seal (*Phoca hispida*): the birth lair and associated structures. **Can. J. Zool.** 53(9):1297-1305.

Solé, M., M. Lenoir, M. Durfort, M. López-Bejar, A. Lombarte, M. van der Schaaer, and M. André. 2013a. Does exposure to noise from human activities compromise sensory information from cephalopod statocysts? **Deep-Sea Res. II** 95:160-181.

Solé, M. M. Lenoir, M. Durfort, M. López-Bejar, A. Lombarte, and M. André. 2013b. Ultrastructural damage of *Loligo vulgaris* and *Illex coindetii* statocysts after low frequency sound exposure. **PLoS One** 8(10):e78825. doi:10.1371/journal.pone.0078825.

Solé, M., P. Sigray, M. Lenoir, M. van der Schaar, E. Lalander, and M. André. 2017. Offshore exposure experiments on cuttlefish indicate received sound pressure and particle motion levels associated with acoustic trauma. **Sci. Rep.** 7:45899. doi:10.1038/srep45899.

Sørensen, K., C. Neumann, M. Dähne, K.A. Hansen, and M. Walhberg. 2020. Gentoo penguins (*Pygoscelis papua*) react to underwater sounds. **R. Soc. Open Sci.** 7:191988. http://dx.doi.org/10.1098/rsos.191988

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

Southall, B.L., T. Rowles, F. Gulland, R.W. Baird, and P.D. Jepson. 2013. Final report of the Independent Scientific Review Panel investigating potential contributing factors to a 2008 mass stranding of melon-headed whales (*Peponocephala electra*) in Antsohihy, Madagascar. Accessed in March 2017 at http://www.agriculturedefensecoalition.org/sites/default/files/file/us_navy_new/271S_8_2013_Independent_Scientific_Review_Panel_Contributing_Factors_Mass_Whale_Stranding_Madagascar_September_25_2013_Final_Report.pdf.

Southall, B.L., D.P. Nowacek, P.J.O. Miller, and P.L. Tyack. 2016. Experimental field studies to measure behavioral responses of cetaceans to sonar. **Endang. Species Res.** 31:293-315.

Stehn, R.A., C.P. Dau, B. Conant, and W.I. Butler, Jr. 1993. Decline of spectacled eiders nesting in western Alaska. **Arctic** 46(3):264-277.

Stephen R. Braund & Associates. 2010. Subsistence mapping of Nuiqsut, Kaktovik, and Barrow. MMS OCS STUDY NUMBER 2009-003. Anchorage, AK: U.S. Department of the Interior, Minerals Management Service, Alaska OCS Region.

Stewart, B.S. and S. Leatherwood. 1985. Minke whale *Balaenoptera acutorostrata* Lacépède, 1804. p. 91-136 *In*: S.H. Ridgway and R. Harrison (eds.), Handbook of marine mammals, Vol. 3: The sirenians and baleen whales. Academic Press, London, UK. 362 p.

Stirling, I. and E.H. McEwan. 1975. The caloric value of whole ringed seals (*Phoca hispida*) in relation to polar bear (*Ursus maritimus*) ecology and hunting behavior. **Can. J. Zool.** 53(8):1021-1027.

Stirling, I., M. Kingsley, and W. Calvert. 1982. The distribution and abundance of seals in the eastern Beaufort Sea, 1974–79. **Can. Wildl. Serv. Occas. Pap.** 47. 25 p.

Stone, C.J. 2015. Marine mammal observations during seismic surveys from 1994–2010. JNCC Rep. No. 463a. 64 p.

Stone, C.J. and M.L. Tasker. 2006. The effects of seismic airguns on cetaceans in UK waters. **J. Cetac. Res. Manage.** 8(3):255-263.

Streever, B., S.W. Raborn, K.H. Kim, A.D. Hawkins, and A.N. Popper. 2016. Changes in fish catch rates in the presence of air gun sounds in Prudhoe Bay, Alaska. **Arctic** [Suppl. 1] 69(4):346–358.

Stroeve, J., M. Serreze, S. Drobot, S. Gearheard, M. Holland, J. Maslanik, W. Meier, and T. Scambos. 2008. Arctic sea ice extent plummets in 2007. **EOS, Trans. Amer. Geophys. Union** 89(2):13-14.

Supin, A., V. Popov, D. Nechaev, E.V. Sysueva, and V. Rozhnov. 2016. Is sound exposure level a convenient metric to characterize fatiguing sounds? A study in beluga whales. p. 1123-1129 *In*: A.N. Popper and A. Hawkins (eds.), The effects of noise on aquatic life II. Springer, New York, NY. 1292 p.

Suryan, R.M., F. Sato, G.R. Balogh, K. David Hyrenbach, P.R. Sievert, and K. Ozaki. 2006. Foraging destinations and marine habitat use of short-tailed albatrosses: A multi-scale approach using first-passage time analysis. **Deep Sea Res. Part II** 53(3-4):370-386.

Suryan, R.M., K.S. Dietrich, E.F. Melvin, G.R. Balogh, F. Sato, and K. Ozaki. 2007. Migratory routes of short-tailed albatrosses: use of exclusive economic zones of North Pacific Rim countries and spatial overlap with commercial fisheries in Alaska. **Biol. Conserv.** 137(3):450-460.

Suydam, R.S. and J.C. George. 1992. Recent sightings of harbor porpoises, *Phocoena phocoena*, near Point Barrow, Alaska. **Can. Field-Nat**. 106(4):489-492.

Suydam, R.S., L.F. Lowry, K.J. Frost, G.M. O'Corry-Crowe, and D. Pikok Jr. 2001. Satellite tracking of eastern Chukchi Sea beluga whales into the Arctic Ocean. **Arctic** 54(3):237-243.

Suydam, R.S., L.F. Lowry, and K.T. Frost. 2005. Distribution and movements of beluga whales from the eastern Chukchi Sea Stock during summer and early autumn. Rep. for the North Slope Borough Dep. Wildl. Manage., Barrow, Alaska.

Suydam, R., J.C. George, B.T. Person, R. Stimmelmayr, T.L. Sformo, L. Pierce, A.L. Von Duyke, L. de Sousa, R. Acker, and G. Sheffield. 2020. Subsistnce harvest of bowhead whales (*Balaena mysticetus*) by Alaskan Natives during 2019. Submitted as paper SC/68B/ASW to the Sci. Comm. Int. Whal. Comm., May 2020.

Sverdrup, H.U., M.W Johnson, and R.H. Fleming. 1942. The oceans. Prentice-Hall, Inc., Englewood Cliffs, NJ. 1087 p.

Swartz, S.L. and M.L. Jones. 1981. Demographic studies and habitat assessment of gray whales, *Eschrichtius robustus,* in Laguna San Ignacio, Baja California, Mexico. U.S. Mar. Mamm. Comm. Rep. MMC-78/03. 34 p. NTIS PB-289737.

Sychenko, O., G. Gailey, R. Racca, A. Rutenko, L. Aerts, and R. Melton. 2017. Gray whale abundance and distribution relative to three seismic surveys near their feeding habitat in 2015. Abstract and presentation at the Society for Marine Mammalogy's 22nd Biennial Conference on the Biology of Marine Mammals, 22-27 October, Halifax, Nova Scotia, Canada.

Tenessen, J.B. and S.E. Parks. 2016. Acoustic propagation modeling indicates vocal compensation in noise improves communication range for North Atlantic right whales. **Endang. Species Res.** 30:225-237.

Teilmann, J., D.M. Wisniewska, M. Johnson, L.A. Miller, U. Siebert, R. Dietz, S. Sveegaard, A. Galatius, and P.T. Madsen. 2015. Acoustic tags on wild harbour porpoises reveal context-specific reactions to ship noise. *In*: 18. Danske Havforskermøde 2015, 28-30 January 2015.

TERA (Troy Environmental Research Associates). 1997. Distribution and abundance of spectacled eiders in the vicinity of Prudhoe Bay, Alaska: 1997 status report. Unpubl. Rep. by Troy Environmental Research Associates, Anchorage, AK.

TERA. 1999. Spectacled eiders in the Beaufort Sea: distribution and timing of use. Unpubl. Rep. by Troy Ecological Research Associates, Anchorage, AK.

Terhune, J.M. and T. Bosker. 2016. Harp seals do not increase their call frequencies when it gets noisier. p. 1149-1153 *In*: A.N. Popper and A. Hawkins (eds.), The effects of noise on aquatic life II. Springer, New York, NY. 1292 p.

Thode, A.M., K.H. Kim, S.B. Blackwell, C.R. Greene, Jr., C.S. Nations, T.L. McDonald, and A.M. Macrander. 2012. Automated detection and localization of bowhead whale sounds in the presence of seismic airgun surveys. **J. Acoust. Soc. Am.** 131(5):3726-3747.

Thode, A.M., S.B. Blackwell, A.S. Conrad, K.H. Kim, T. Marques, L. Thomas, C.S. Oedekoven, D. Harris, and K. Bröker. 2020. Roaring and repetition: How bowhead whales adjust their call density and source level

(Lombard effect) in the presence of natural and seismic airgun survey noise. **J. Acoust. Soc. Am.**147(3):2061-2080.

Thoman, R.L., J. Richter-Menge, and M.L. Druckenmiller (eds.) 2020. Arctic report card 2020. Accessed January 2021 at https://arctic.noaa.gov/Portals/7/ArcticReportCard/Documents/ArcticReportCard_full_report2020.pdf

Thomas, T., W.R. Koski, and D.S. Ireland. 2010. Chukchi Sea nearshore aerial surveys. Chapter 4 *In*: D.W. Funk, D.S. Ireland, R. Rodrigues, and W.R. Koski (eds.), Joint monitoring program in the Chukchi and Beaufort seas, open water seasons, 2006–2008. LGL Alaska Rep. P1050-2. Rep. from LGL Alaska Research Associates, Inc., LGL Ltd., Greeneridge Sciences, Inc., and JASCO Research, Ltd., for Shell Offshore, Inc. and other Industry contributors, National Marine Fisheries Service, and U.S. Fish and Wildlife Service. 506 p. + app.

Thompson, D., M. Sjöberg, E.B. Bryant, P. Lovell, and A. Bjørge. 1998. Behavioural and physiological responses of harbour (*Phoca vitulina*) and grey (*Halichoerus grypus*) seals to seismic surveys. Abstr. World Mar. Mamm. Sci. Conf., Monaco.

Thompson, P.M., K.L. Brookes, I.M. Graham, T.R. Barton, K. Needham, G. Bradbury, and N.D. Merchant. 2013. Short-term disturbance by a commercial two-dimensional seismic survey does not lead to long-term displacement of harbour porpoises. **Proc. Royal Soc. B** 280: 20132001.

Tomilin, A.G. 1957. Mammals of the U.S.S.R. and adjacent countries. Vol, 9: Cetaceans. Israel Progr. Sci. Transl. (1967), Jerusalem. 717 p. NTIS TT 65-50086.

Tougaard, J., A.J. Wright, and P.T. Madsen. 2015. Cetacean noise criteria revisited in light of proposed exposure limits for harbour porpoises. **Mar. Poll. Bull.** 90(1-2):196-208.

Tougaard, J., A.J. Wright, and P.T. Madsen. 2016. Noise exposure criteria for harbor porpoises. p. 1167-1173 *In*: A.N. Popper and A. Hawkins (eds.), The effects of noise on aquatic life II. Springer, New York, NY. 1292 p.

Treacy, S.D. 1993. Aerial surveys of endangered whales in the Beaufort Sea, fall 1992. OCS Study MMS 93-0023. U.S. Minerals Manage. Serv., Anchorage, AK. 136 p.

Treacy, S.D. 1997. Aerial surveys of endangered whales in the Beaufort Sea, fall 1996. OCS Study MMS 97-0016. U.S. Minerals Manage. Serv., Anchorage, AK. 115 p. NTIS PB97-194690.

Treacy, S.D., J.S. Gleason, and C.J. Cowles. 2006. Offshore distances of bowhead whales (*Balaena mysticetus*) observed during fall in the Beaufort Sea, 1982–2000: an alternative interpretation. **Arctic** 59(1):83-90.

Troy, D.M. 2003. Molt migration of spectacled eiders in the Beaufort Sea region. Unpubl. Rep. by Troy Ecological Research Associates, Anchorage, AK, for BP Exploration (Alaska) Inc., Anchorage, AK. 17p.

Tsujii, K., M. Otsuki, T. Akamatsu, I. Matsuo, K. Amakasu, M. Kitamura, T. Kikuchi, K. Miyashita, and Y. Mitani. 2016. The migration of fin whales into the southern Chukchi Sea as monitored with passive acoustics. **ICES J. Mar. Sci.** 73(8):2085-2092.

Tyack, P.L. and V.M. Janik. 2013. Effects of noise on acoustic signal production in marine mammals. p. 251-271 *In*: H. Brumm (ed.), Animal communication and noise. Springer, Berlin, Heidelberg, Germany. 453 p.

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

UN (United Nations Atlas of the Oceans). 2016. Arctic Ocean LME. UN Atlas of the Oceans. Accessed January 2021 at http://www.oceansatlas.org/subtopic/en/c/871/

UNEP-WCMC (United Nations Environment Programme-World Conservation Monitoring Centre). 2020. Convention on International Trade in Endangered Species of Wild Flora and Fauna. Appendices I, II, and III. Accessed in December 2020 at https://www.cites.org/eng/app/appendices.php.

USFWS (U.S. Fish and Wildlife Service). 2002. Steller's eider recovery plan. Fairbanks, Alaska. 27 p.

USFWS. 2008a. Endangered and threatened wildlife and plants; designation of threatened status for the polar bear (*Ursus maritimus*) throughout its range; Final Rule. **Fed. Reg.** 73(95, 15 May):28212-28303.

USFWS. 2008b. Short-tailed albatross recovery plan. U.S. Dept. Interior, U.S. Fish and Wildlife Service, Anchorage, AK. 105 p.

USFWS. 2010. Endangered and threatened wildlife and plants; designation of critical habitat for the polar bear (*Ursus maritimus*) in the United States; Final Rule. **Fed. Reg.** 75(234, 7 Dec.):76086-76137.

USFWS. 2020a. Polar bear (*Ursus maritimus*): Southern Beaufort Sea stock. Accessed in January 2021 at https://www.fws.gov/r7/fisheries/mmm/stock/final_sbs_polar_bear_sar.pdf

USFWS. 2020b. Polar bear (*Ursus maritimus*): Chukchi/Bering Seas Stock. Accessed in January 2021 at https://www.fws.gov/r7/fisheries/mmm/stock/final_cbs_polar_bear_sar.pdf

U.S. Navy. 2019a. 2018-2019 Office of Naval Research Arctic Research Activities Incidental Harassment Authorization After Action Report. Available at https://media.fisheries.noaa.gov/dam-migration/onr_arcticresearch_2018iha_monrep_opr1.pdf.

U.S. Navy. 2019b. Supplemental Environmental Assessment/Overseas Environmental Assessment for Ice Exercise. Commander, U.S. Fleet Forces Command.

van Beest, F.M., J. Teilmann, L. Hermannsen, A. Galatius, L. Mikkelsen, S. Sveegaard, J.D. Balle, R. Dietz, J. Nabe-Nielsen. 2018. Fine-scale movement responses of free-ranging harbour porpoises to capture, tagging and short-term noise pulses from a single airgun. **R. Soc. Open Sci.** 5:170110. doi:10.1098/rsos.170110.

van Meurs, R. and J.F. Splettstoesser. 2003. Letter to the editor–farthest north polar bear. **Arctic** 56(3):309.

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

Vibe, C. 1950. The marine mammals and the marine fauna in the Thule District (northwest Greenland) with observations on ice conditions in 1939–41. **Medd. Grønl.** 150:1-115.

Vilela, R., U. Pena, R. Esteban, and R. Koemans. 2016. Bayesian spatial modeling of cetacean sightings during a seismic acquisition survey. **Mar. Poll. Bull.** 109(1):512-520.

Vladimirov, V.A., S.P. Starodymov, A.G. Afanasyev-Grigoriyev, and J. Muir. 2008. Distribution and abundance of Korean stock gray whales in the waters of northeastern Sakhalin during June-October 2007. Final Report by the All-Russian Research Institute of Fisheries and Oceanography (VNIRO), Moscow, Russia, the Institute of Marine Biology FEB RAS, Vladivostok, Russia, and LGL Limited, Sidney, Canada for Exxon Neftegas Limited and Sakhalin Energy Investment Company, Yuzhno-Sakhalinsk.

Von Duyke, A.L., D.C. Douglas, J.K. Herreman, and J.A. Crawford. 2020. Ringed seal (*Pusa hispida*) seasonal movements, diving, and haul-out behavior in the Beaufort, Chukchi, and Bering seas (2011–2017). **Ecol. Evol.** 10(12):5595-5616.

Wade, P.R. 2017. Estimates of abundance and migratory destination for North Pacific humpback whales in both summer feeding areas and winter mating and calving areas revision of estimates in SC/66b/IA21. Paper SC/A17/NP/11 presented to the Int. Whal. Comm.

Wale, M.A., S.D. Simpson, and A.N. Radford. 2013a. Size-dependent physiological responses of shore crabs to single and repeated playback of ship noise. **Biol. Lett.** 9:20121194.

Wale, M.A., S.D. Simpson, and A.N. Radford. 2013b. Noise negatively affects foraging and antipredator behaviour in shore crabs. **Anim. Behav.** 86:111-118.

Wartzok, D., A.N. Popper, J. Gordon, and J. Merrill. 2004. Factors affecting the responses of marine mammals to acoustic disturbance. **Mar. Technol. Soc. J.** 37(4):6-15.

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

Weilgart, L.S. 2007. A brief review of known effects of noise on marine mammals. **Int. J. Comp. Psychol.** 20:159-168.

Weilgart, L.S. 2014. Are we mitigating underwater noise-producing activities adequately? A comparison of Level A and Level B cetacean takes. Working pap. SC/65b/E07. Int. Whal. Comm., Cambridge, UK. 17 p.

Weilgart, L. 2017a. Din of the deep: noise in the ocean and its impacts on cetaceans. Pages 111-124 *In*: A. Butterworth (ed.), Marine mammal welfare human induced change in the marine environment and its impacts on marine mammal welfare. Springer.

Weilgart, L.S. 2017b. The impact of ocean noise pollution on fish and invertebrates. Report for OceanCare, Switzerland. 23 p.

Weir, C.R. and S.J. Dolman. 2007. Comparative review of the regional marine mammal mitigation guidelines implemented during industrial seismic surveys, and guidance towards a worldwide standard. **J. Int. Wildl. Law Policy** 10(1):1-27.

Weller, D.W., B. Wursig, A.L. Bradford, A.M. Burdin, S.A. Blokhin, H. Minakuchi, and R.L. Bronwell, Jr. 1999. Gray whales (*Eschrichtius robustus*) off Sakhalin island, Russia: seasonal and annual patterns of occurrence. **Mar. Mamm. Sci.** 15(4):1208-1227.

Weller, D.W., S.H. Reeve, A.M. Burdin, B. Würsig, and R.L. Brownell, Jr. 2002a. A note on spatial distribution of western gray whales (*Eschrichtius robustus*) off Sakhalin island, Russia in 1998. **J. Cetacean Res. Manage.** 4(1):13-17.

Weller, D.W., Y.V. Ivashchenko, G.A. Tsidulko, A.M. Burdin, and R.L. Brownell, Jr. 2002b. Influence of seismic surveys on western gray whales off Sakhalin Island, Russia in 2001. Paper SC/54/BRG14, IWC, Western Gray Whale Working Group Meet., 22-25 Oct., Ulsan, South Korea. 12 p.

Weller, D.W., S.H. Rickards, A.L. Bradford, A.M. Burdin, and R.L. Brownell, Jr. 2006a. The influence of 1997 seismic surveys on the behavior of western gray whales off Sakhalin Island, Russia. Paper SC/58/E4 presented to the IWC Scient. Commit., IWC Annu. Meet., 1-13 June, St. Kitts.

Weller, D.W., G.A. Tsidulko, Y.V. Ivashchenko, A.M. Burdin and R.L. Brownell Jr. 2006b. A re-evaluation of the influence of 2001 seismic surveys on western gray whales off Sakhalin Island, Russia. Paper SC/58/E5 presented to the IWC Scient. Commit., IWC Annu. Meet., 1-13 June, St. Kitts.

Weller, D.W., A.L. Bradford, H. Kato, T. Bando, S. Ohtani, A.M. Burdin, and R.L. Brownell, Jr. 2008. Photographic match of a western gray whale between Sakhalin Island, Russia, and Honshu, Japan: first link between feeding ground and migratory corridor. **J. Cetacean Res. Manage**. 10:89-91.

Weller, D.W., A. Klimek, A.L. Bradford, J. Calambokidis, A.R. Lang, B. Gisborne, A.M. Burdin, W. Szaniszlo, J. Urbán, A.G.G. Unzueta, S. Swartz, and R.L. Brownell, Jr. 2012. Movements of gray whales between the western and eastern North Pacific. **Endang. Species Res.** 18:193-199.

Weller, D.W., S. Bettridge, R.L. Brownell Jr., J.L. Laake, J.E. Moore, P.E. Rosel, B.L. Taylor, and P.R. Wade. 2013. Report of the national Marine Fisheries Service Gray Whale Stock Identification Workshop. U.S. Dep. Commer., NOAA Tech. Memo. NOAA-TM-NMFS-SWFSC-507.

Wensveen, P.J., L.A.E. Huijser, L. Hoek, and R.A. Kastelein. 2014. Equal latency contours and auditory weighting functions for the harbour porpoise (*Phocoena phocoena*). **J. Exp. Biol.** 217(3):359-369.

Wensveen, P.J., A.M. von Benda-Beckmann, M.A. Ainslie, F.P.A. Lam, P.H. Kvadsheim, P.L. Tyack, and P.J.O. Miller. 2015. How effectively do horizontal and vertical response strategies of long-finned pilot whales reduce sound exposure from naval sonar? **Mar. Environ. Res.** 106:68-81.

Wiley, D.N., C.A. Mayo, E.M. Maloney, and M.J. Moore. 2016. Vessel strike mitigation lessons from direct observations involving two collisions between noncommercial vessels and North Atlantic right whales (*Eubaleana glacialis*). **Mar. Mammal Sci.** 32(4):1501-1509.

Williams, R., D. Cholewiak, C.W. Clark, C. Erbe, J.C. George, R.C. Lacy, R. Leaper, S.E. Moore, L. New, E.C.M. Parsons, H.C. Rosenbaum, T.K. Rowles, M.P. Simmonds, R. Stimmelmayr, R.S. Suydam, and A.J. Wright. 2020. Chronic ocean noise and cetacean population models. **J. Cetacean Res. Manage.** 21:85-94.

Williams, T.M, W.A. Friedl, M.L. Fong, R.M. Yamada, P. Sideivy, and J.E. Haun. 1992. Travel at low energetic cost by swimming and wave-riding bottlenose dolphins. **Nature** 355(6363):821-823.

Winn, H.E. and N.E. Reichley. 1985. Humpback whale *Megaptera novaeangliae* (Borowski, 1781). p. 241-273 *In*: S.H. Ridgway and R. Harrison (eds.), Handbook of marine mammals, Vol. 3: The sirenians and baleen whales. Academic Press, London, UK. 362 p.

Winsor, M.H., L.M. Irvine, and B.R. Mate. 2017. Analysis of the spatial distribution of satellite-tagged sperm whales (*Physeter macrocephalus*) in close proximity to seismic surveys in the Gulf of Mexico. **Aquatic Mamm.** 43(4):439-446.

Wisniewska, D.M., M. Johnson, J. Teilmann, U. Siebert, A. Galatius, R. Dietz, and P.T. Madsen. 2018. High rates of vessel noise disrupt foraging in wild harbour porpoises (*Phocoena phocoena*). **Proc. R. Soc. B** 285:20172314.

Wittekind, D., J. Tougaard, P. Stilz, M. Dähne, K. Lucke, C.W. Clark, S. von Benda-Beckmann, M. Ainslie, and U. Siebert. 2016. Development of a model to assess masking potential for marine mammals by the use of airguns in Antarctic waters. p. 1243-1249 *In*: A.N. Popper and A. Hawkins (eds.), The effects of noise on aquatic life II. Springer, New York, NY. 1292 p.

Wole, O.G. and E.F. Myade. 2014. Effect of seismic operations on cetacean sightings off-shore Akwa Ibom State, south-south, Nigeria. **Int. J. Biol. Chem. Sci.** 8(4):1570-1580.

Woodgate, R.A., K. Aagard, R.D. Muench, J. Gunn, G. Bork, B. Rudels, A.T. Roach and U. Schauer. 2001. The Arctic Ocean boundary current along the Eurasian slope and the adjacent Lomonosov Ridge: water mass properties, transports and transformations from moored instruments. **Deep-Sea Res., Part I** 48:1757-1792.

Wright, A.J. 2014. Reducing impacts of human ocean noise on cetaceans: knowledge gap analysis and recommendations. 98 p. World Wildlife Fund Global Arctic Programme, Ottawa, ON.

Wright, A.J. and A.M. Consentino. 2015. JNCC guidelines for minimizing the risk of injury and disturbance to marine mammals from seismic surveys: we can do better. **Mar. Poll. Bull.** 100(1):231-239. doi:10.1016/j.marpolbul.2015.08.045.

Wright, A.J. and L.A. Kyhn. 2014. Practical management of cumulative anthropogenic impacts for working marine examples. **Conserv. Biol.** 29(2):333-340. https://doi.org/10.1111/cobi.12425.

Wright, A.J., T. Deak, and E.C.M. Parsons. 2011. Size matters: management of stress responses and chronic stress in beaked whales and other marine mammals may require larger exclusion zones. **Mar. Poll. Bull.** 63(1-4):5-9.

Würsig, B., S.K. Lynn, T.A. Jefferson, and K.D. Mullin. 1998. Behaviour of cetaceans in the northern Gulf of Mexico relative to survey ships and aircraft. **Aquatic Mamm.** 24(1):41-50.

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

Yazvenko, S.B., T.L. McDonald, S.A. Blokhin, S.R. Johnson, S.K. Meier, H.R. Melton, M.W. Newcomer, R.M. Nielson, V.L. Vladimirov, and P.W. Wainwright. 2007a. Distribution and abundance of western gray whales during a seismic survey near Sakhalin Island, Russia. **Environ. Monit. Assess.** 134(1-3):45-73. doi:10.1007/s10661-007-9809-9.

Yazvenko, S.B., T.L. McDonald, S.A. Blokhin, S.R. Johnson, H.R. Melton, and M.W. Newcomer. 2007b. Feeding activity of western gray whales during a seismic survey near Sakhalin Island, Russia. **Environ. Monit. Assess**. 134(1-3): 93-106. doi:10.1007/s10661-007-9810-3.

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

Yu, Z.H., H.S. Yang, B.Z. Liu, Q. Xu, K. Xing, L.B. Zhang. 2010. Growth, survival and immune activity of scallops, *Chlamys farreri* Jones et Preston, compared between suspended and bottom culture in Haizhou Bay, China. **Aquacult. Res.** 41:814-827.

Yurk, H., L. Barrett Lennard, J.K.B. Ford, and C.O. Matkin. 2002. Cultural transmission within maternal lineages: vocal clans in resident killer whales in southern Alaska. **Anim. Behav.** 63:1103-1119.

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

Zharikov, K.A., D.I. Litovka, and E.V. Vereshagin. 2020. Aboriginal subsistence whaling in the Russian Federation in 2019. Unpubl. doc. submitted to Int. Whal. Comm. Scientific Committee (SC/68a/ASW/04). 2 p.

List of Appendices

APPENDIX A: DETERMINATION OF MITIGATION ZONES

APPENDIX A: DETERMINATION OF MITIGATION ZONES

During the planning phase, mitigation zones for the proposed marine seismic surveys were calculated based on modeling by L-DEO for the Level A exclusion zones (EZ) and the Level B (160 dB re 1µPa_{rms}) threshold. 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 airgun arrays; all models used a 9-m tow depth. The L-DEO 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).

Propagation measurements of pulses from a 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 L-DEO modeling 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.

The proposed surveys would acquire data with a 2 G-airgun and 6 G-airgun array at a maximum tow depth of 9 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 2 G-airgun (Fig. A-1) and 6 G-airgun (Fig. A-2) array (Table 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).

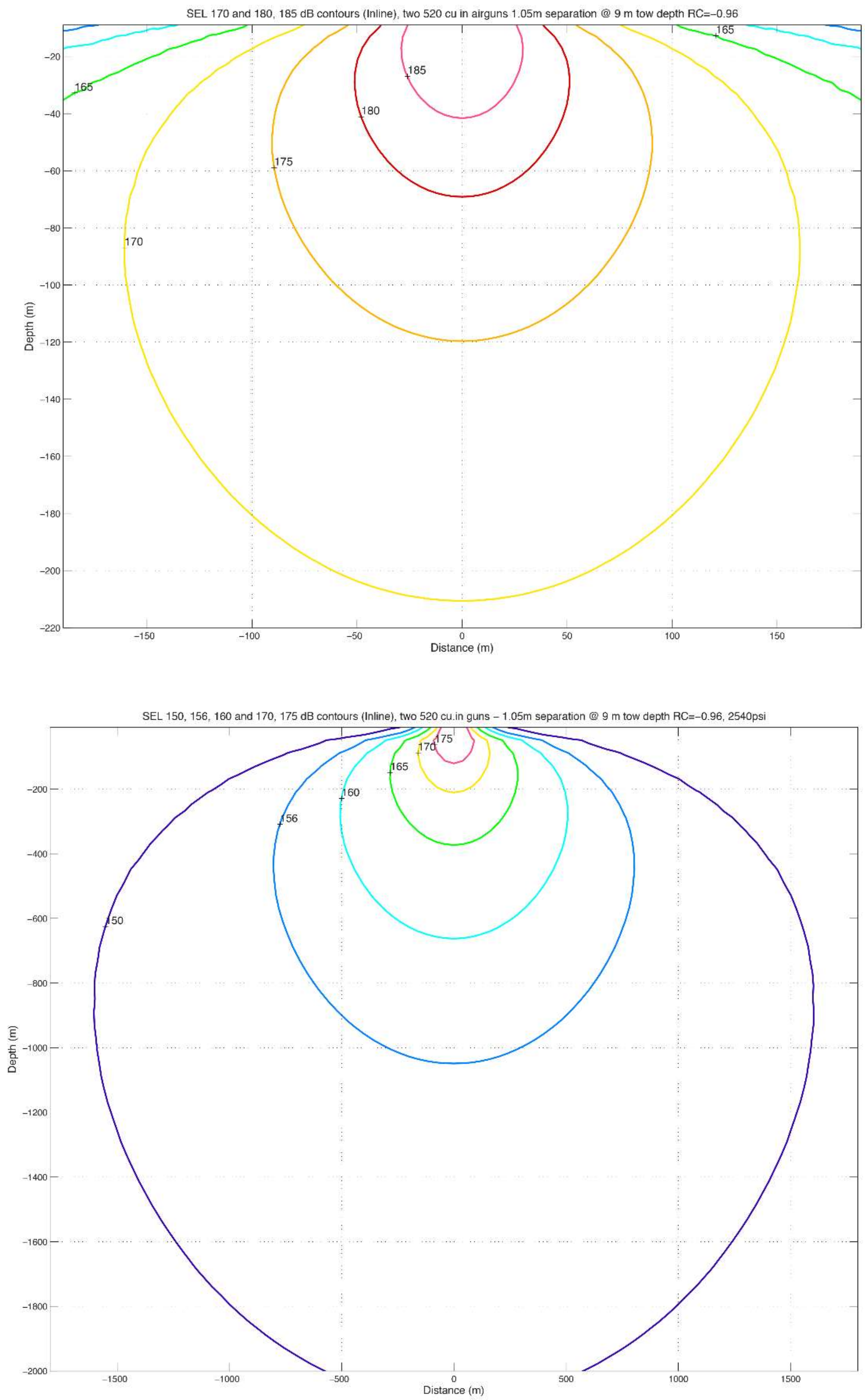

FIGURE A-1. Modeled deep-water received sound exposure levels (SELs) from the 2 G-airgun array at a 9-m tow depth planned for use during the proposed surveys in the Arctic Ocean. Received rms levels (SPLs) are expected to be ~10 dB higher. For example, the radius to the 150-dB SEL isopleth is a proxy for the 160-dB rms isopleth. The upper plot is a zoomed-in version of the lower plot.

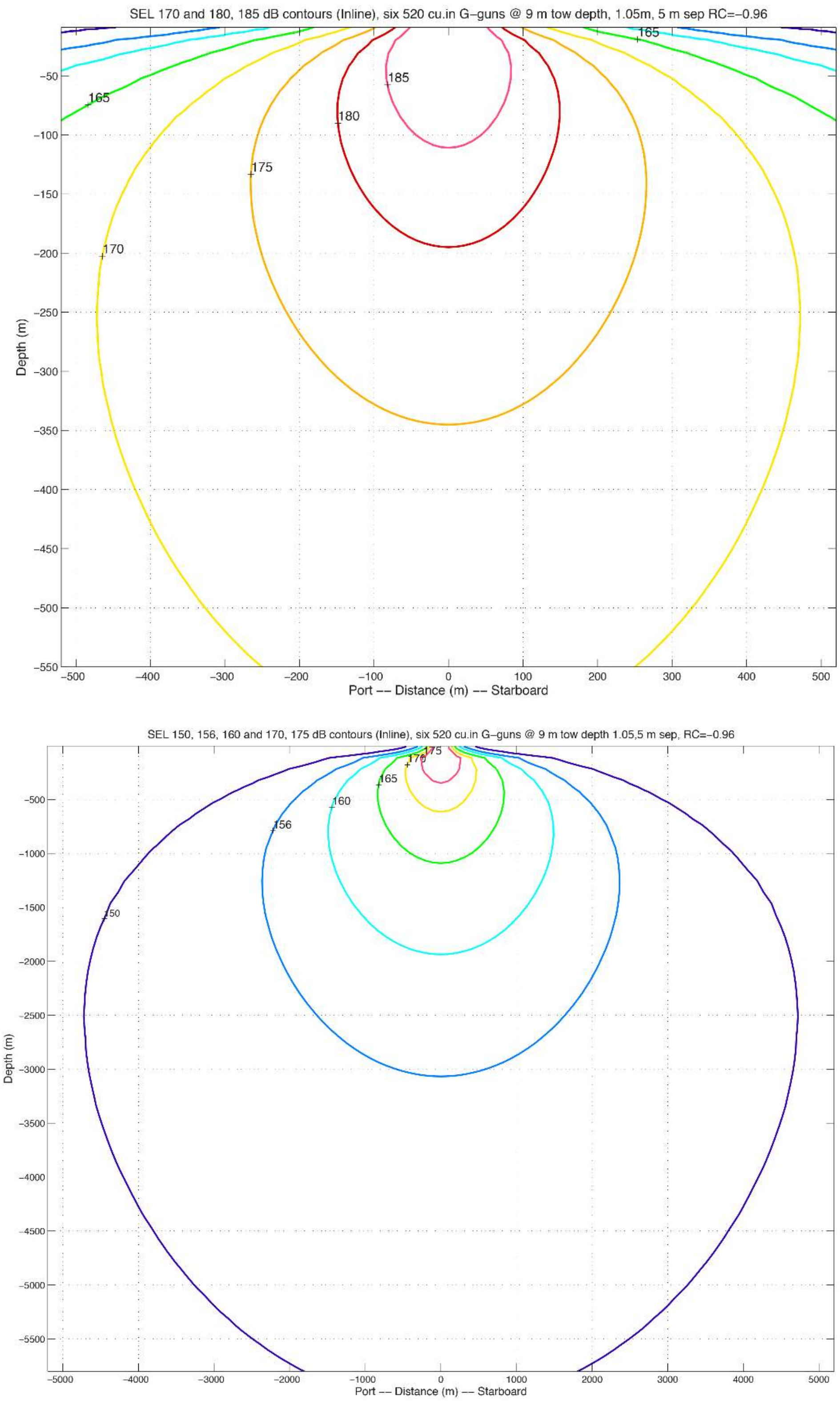

FIGURE A-2. Modeled deep-water received sound exposure levels (SELs) from the 6 G-airgun array at a 9-m tow depth planned for use during the proposed surveys in the Arctic Ocean. Received rms levels (SPLs) are expected to be ~10 dB higher. For example, the radius to the 150-dB SEL isopleth is a proxy for the 160-dB rms isopleth. The upper plot is a zoomed-in version of the lower plot.

TABLE A-1. Level B. Predicted distances to which sound levels ≥160-dB could be received during the proposed surveys in the Arctic Ocean. The 160-dB criterion applies to all marine mammal hearing groups.

Source and Volume[1]	Tow Depth (m)	Water Depth (m)	Predicted distances (in m) to the 160-dB Received Sound Level
Two 520 in^3 G-airguns, 1040 in^3	9	>1000 m	1604[2]
		100–1000 m	2406[3]
Six 520 in^3 G-airguns, 3120 in^3	9	>1000 m	4640[2]
		100–1000 m	6960[3]

[1] Modeled at 2540 psi.
[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.

Of note is that five separate comparisons conducted of the L-DEO model with *in situ* received levels[2] have confirmed that the L-DEO model generated conservative mitigation radii, resulting in significantly larger radii than required by 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 noise exposure criteria for marine mammals account for 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 guidance incorporates marine mammal auditory weighting functions (Fig. A-3) 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/other non-phocid carnivores 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 NMFS guidance did not alter the current threshold, 160 dB re 1µPa_{rms}, for Level B harassment (behavior). 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. 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.

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

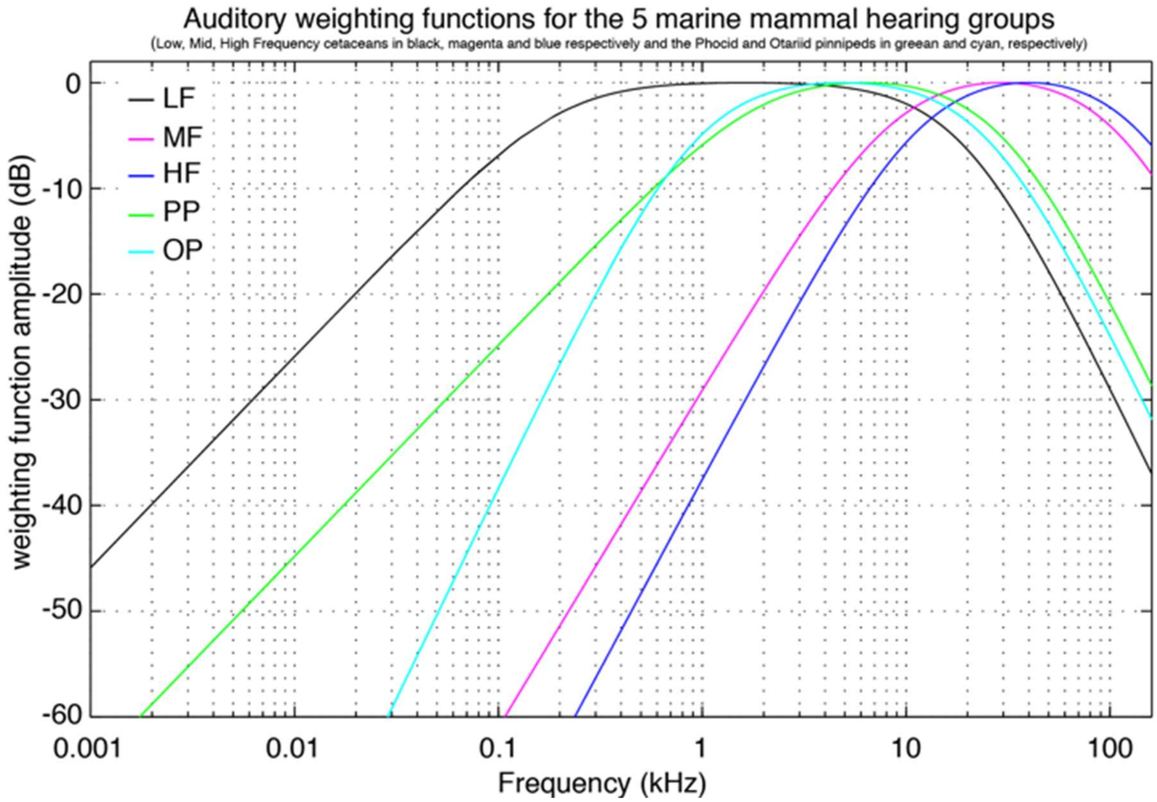

FIGURE A-3. Auditory weighting functions for five marine mammal hearing groups from the NMFS Technical Guidance.

The SEL_{cum} for the arrays are 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). Repetition rates of 15 s and 60 s were used for the 2 G-airgun and 6 G-airgun arrays, respectively, along with a source velocity of 2.315 m/s, as inputs to the NMFS User Spreadsheet for calculating the distances to the SEL_{cum} PTS thresholds (Level A) for the airgun arrays.

For the LF cetaceans, we estimated an 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 (e.g., the maximum isopleth was 39.87 m from the 2 G-airgun array; Table A-2). We then ran the modeling for a single shot with the LF cetacean weighting function applied to the full spectrum (e.g., the maximum isopleth was 13.79 m from the 2 G-airgun source). The difference between these values provides an adjustment factor and assumes a propagation of $20\log_{10}$(Radial distance), in this case 9.22 dB for the 2 G-airgun array. The radial distances are used to calculate the modified farfield values, whereas the radius is the vertical projection to the sea surface and distance from the source laterally, which is used for mitigation purposes.

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

For the 2 G-airgun array, the results for single shot SEL source level modeling are shown in Table A-2. The weighting function calculations, thresholds for SEL_{cum}, and the distances to the PTS thresholds for the 2 G-airgun array are shown in Table A-3. Figure A-4 shows the impact of weighting functions by hearing group. Figures A-5–A-7 show the modeled received sound levels for single shot SEL without applying auditory weighting functions for various hearing groups. Figure A-8 shows the modeled received sound levels for single shot SEL with weighting for LF cetaceans. The thresholds for Peak SPL_{flat} for the 2 G-airgun array, as well as the distances to the PTS thresholds, are shown in Table A-4. Figures A-9–A-10 show the modeled received sound levels to the Peak SPL_{flat} thresholds, for a single shot.

For the 6 G-airgun array, the results for single shot SEL source level modeling are shown in Table A-5. The weighting function calculations, thresholds for SEL_{cum}, and the distances to the PTS thresholds for the 6 G-airgun array are shown in Table A-6. Figure A-11 shows the impact of weighting functions by hearing group. Figures A-12–A-14 show the modeled received sound levels for single shot SEL without applying auditory weighting functions for various hearing groups. Figure A-15 shows the modeled received sound levels for single shot SEL with weighting for LF cetaceans. The thresholds for Peak SPL_{flat} for the 6 G-airgun array, as well as the distances to the PTS thresholds, are shown in Table A-7. Figures A-16–A-17 show the modeled received sound levels to the Peak SPL_{flat} thresholds, for a single shot.

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

SEL_{cum} Threshold	183	185	155	185	203
Radial Distance (m) (no weighting	39.8732	31.5298	1054.7	31.5298	4.2518
Modified Farfield SEL	215.0136	214.9744	215.4626	214.9744	215.5715
Radial Distance (m) (with weighting function)	13.7936	N.A.	N.A.	N.A.	N.A.
Adjustment (dB)	-9.22	N.A.	N.A.	N.A.	N.A.

N.A. means not applicable or not available.

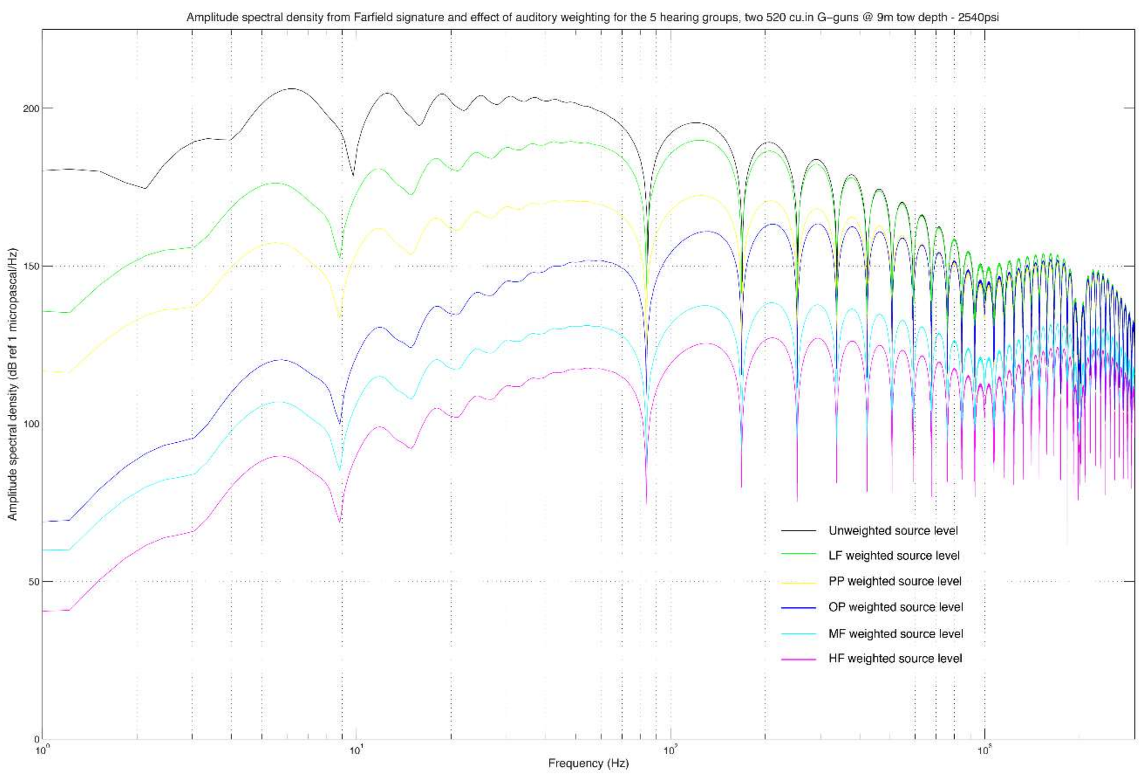

FIGURE A-4. Modeled amplitude spectral density of the 2 G-airgun array farfield signature. Amplitude spectral density before (black) and after (colors) applying the auditory weighting functions for LF, MF, and HF cetaceans, Phocid Pinnipeds (PP), and Otariid Pinnipeds (OP). Modeled spectral levels are 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 modified farfield SEL source level modeling for the 2 G-airgun array with weighting function calculations for the SEL_{cum} criteria, as well as resulting isopleths to thresholds for hearing groups.

F: MOBILE SOURCE: Impulsive, Intermittent (SAFE DISTANCE METHODOLOGY)

VERSION 1.1: Aug-16

KEY	
(green)	Action Proponent Provided Information
(pink)	NMFS Provided Information (Acoustic Guidance)
(blue)	Resultant Isopleth

STEP 1: GENERAL PROJECT INFORMATION

PROJECT TITLE	Bernie Coakley
PROJECT/SOURCE INFORMATION Please include any assumptions	source : 2 x 520 cu.in G-guns at a 9m towed depth - (1.05 m separation) - 4.5 knots, shot interval is 15s. RMS SPL, Peak SPL and SELcum derived from the farfield signature
PROJECT CONTACT	

STEP 2: WEIGHTING FACTOR ADJUSTMENT

Specify if relying on source-specific WFA, alternative weighting/dB adjustment, or if using default value

Weighting Factor Adjustment (kHz)[¥]	User defined	Override WFA: Using LDEO modeling

[¥] Broadband: 95% frequency contour percentile (kHz) OR Narrowband: frequency (kHz); For appropriate default WFA: See INTRODUCTION tab

† If a user relies on alternative weighting/dB adjustment rather than relying upon the WFA (source-specific or default), they may override the Adjustment (dB) (row 62), and enter the new value directly. However, they must provide additional support and documentation supporting this modification.

* BROADBAND Sources: Cannot use WFA higher than maximum applicable frequency (See GRAY tab for more information on WFA applicable frequencies)

STEP 3: SOURCE-SPECIFIC INFORMATION

NOTE: Choose either F1 OR F2 method to calculate isopleths (not required to fill in sage boxes for both)

NOTE: LDEO modeling relies on Method F2

F2: ALTERNATIVE METHOD† TO CALCULATE PK and SEL_{cum} (SINGLE STRIKE/SHOT/PULSE EQUIVALENT)

SEL_{cum}

Source Velocity (meters/second)	2.315
1/Repetition rate^ (seconds)	15

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

^Time between onset of successive pulses.

Modified farfield SEL	**215.0136**	**214.9744**	**215.4626**	**214.9744**	**215.5715**
Source Factor	**2.1148E+20**	**2.09579E+20**	**2.34514E+20**	**2.09579E+20**	**2.40469E+20**

RESULTANT ISOPLETHS*

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

Hearing Group	Low-Frequency Cetaceans	Mid-Frequency Cetaceans	High-Frequency Cetaceans	Phocid Pinnipeds	Otariid Pinnipeds
SEL_{cum} Threshold	183	185	155	185	203
PTS SEL_{cum} Isopleth to threshold (meters)	**17.2**	**0.0**	**0.0**	**0.2**	**0.0**

WEIGHTING FUNCTION CALCULATIONS

Weighting Function Parameters	Low-Frequency Cetaceans	Mid-Frequency Cetaceans	High-Frequency Cetaceans	Phocid Pinnipeds	Otariid Pinnipeds	
a	1	1.6	1.8	1	2	
b	2	2	2	2	2	
f_1	0.2	8.8	12	1.9	0.94	
f_2	19	110	140	30	25	
C	0.13	1.2	1.36	0.75	0.64	
Adjustment (dB)†	-9.22	-57.71	-66.94	-26.96	-33.60	OVERIDE Using LDEO Model

†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-4).

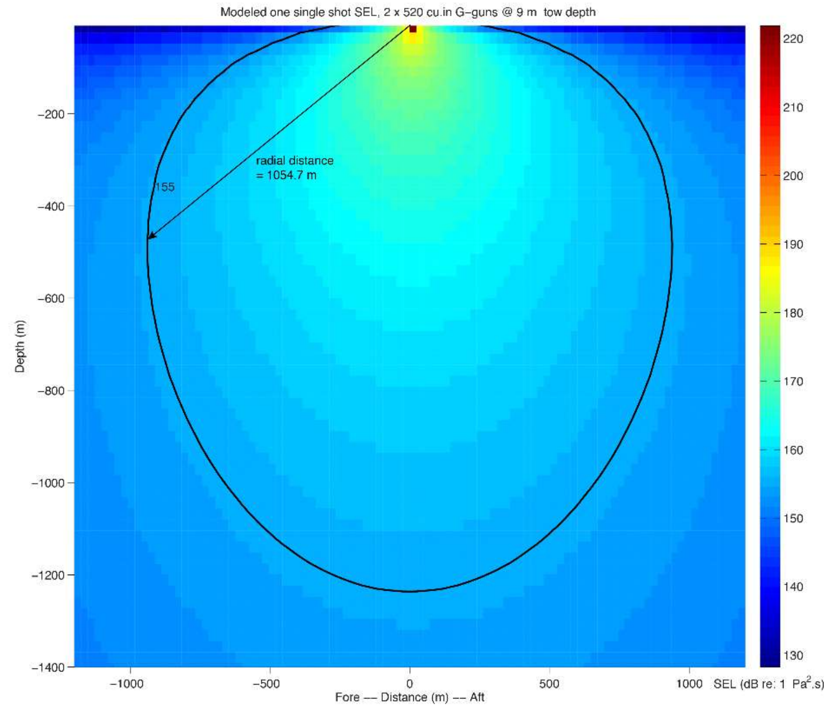

FIGURE A-5. Modeled received sound levels (SELs) in deep water from the 2 G-airgun array. The plot provides the radial distance from the geometrical center of the source array to the 155-dB SEL isopleth.

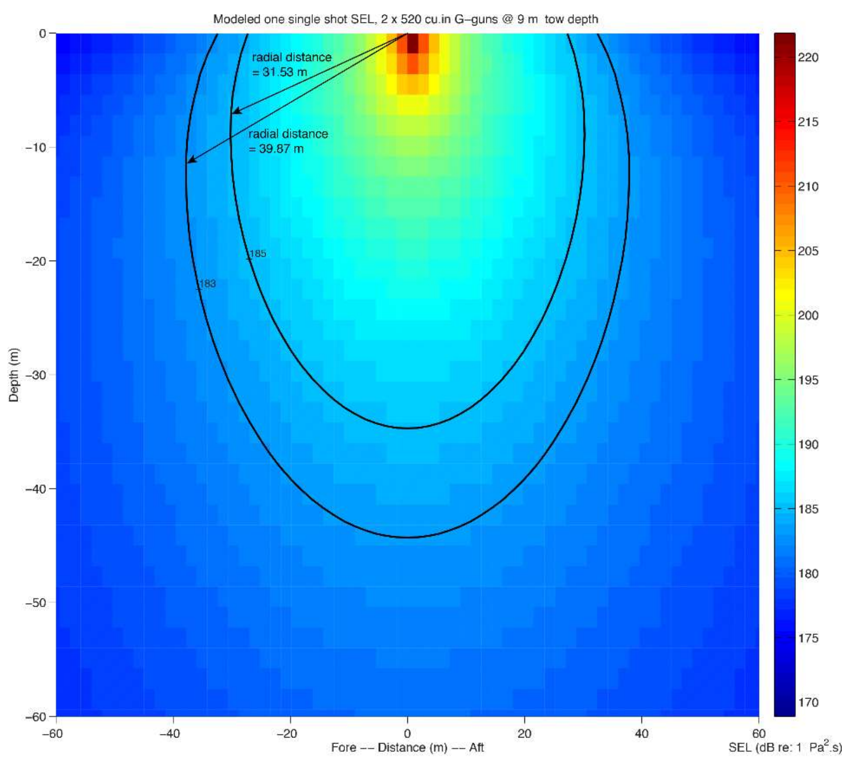

FIGURE A-6. Modeled received sound levels (SELs) in deep water from the 2 G-airgun array. The plot provides the radial distance from the geometrical center of the source array to the 183–185-dB SEL isopleths.

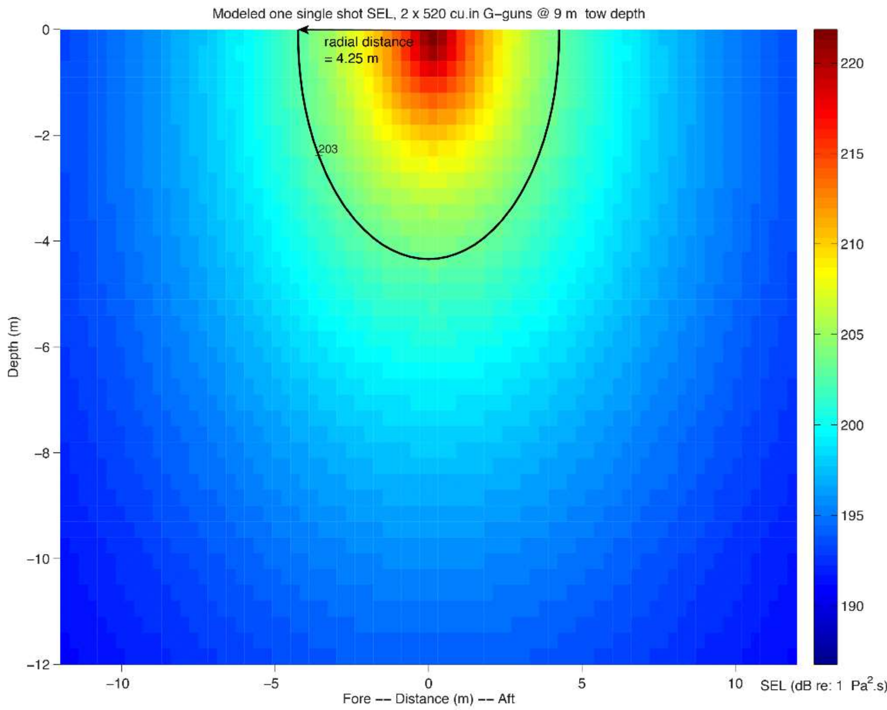

FIGURE A-7. Modeled received sound levels (SELs) in deep water from the 2 G-airgun array. The plot provides the radial distance from the geometrical center of the source array to the 203-dB SEL isopleth.

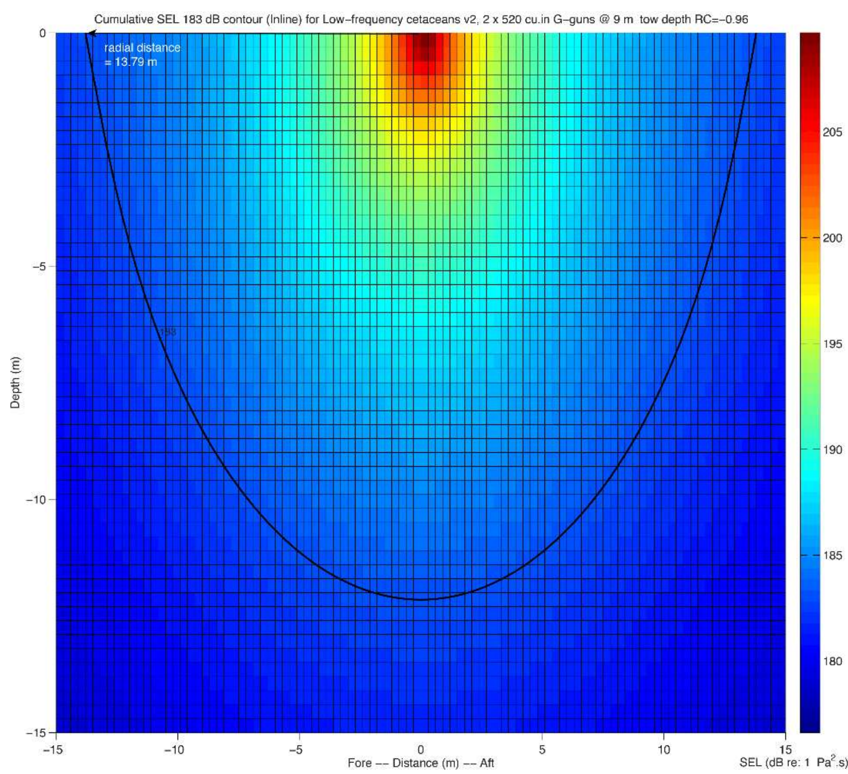

FIGURE A-8. Modeled received sound exposure levels (SELs) from the 2 G-airgun array at a 9-m tow depth, after applying the auditory weighting function for the LF cetaceans hearing group following the NMFS Technical Guidance. The plot provides the radial distance to the 183-dB SEL_{cum} isopleth for one shot. The difference in radial distances between Fig. A-4 and this figure allows us to estimate the adjustment in dB.

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

Hearing Group	Low-Frequency Cetaceans	Mid-Frequency Cetaceans	High-Frequency Cetaceans	Phocid Pinnipeds	Otariid Pinnipeds
Peak Threshold	**219**	**230**	**202**	**218**	**232**
Radial Distance to Threshold (m)	10.29	2.86	72.92	11.55	2.26
PTS Peak Isopleth (Radius) to Threshold (m)	10.29	2.86	72.83	11.55	2.26

N.A. means not applicable or not available.

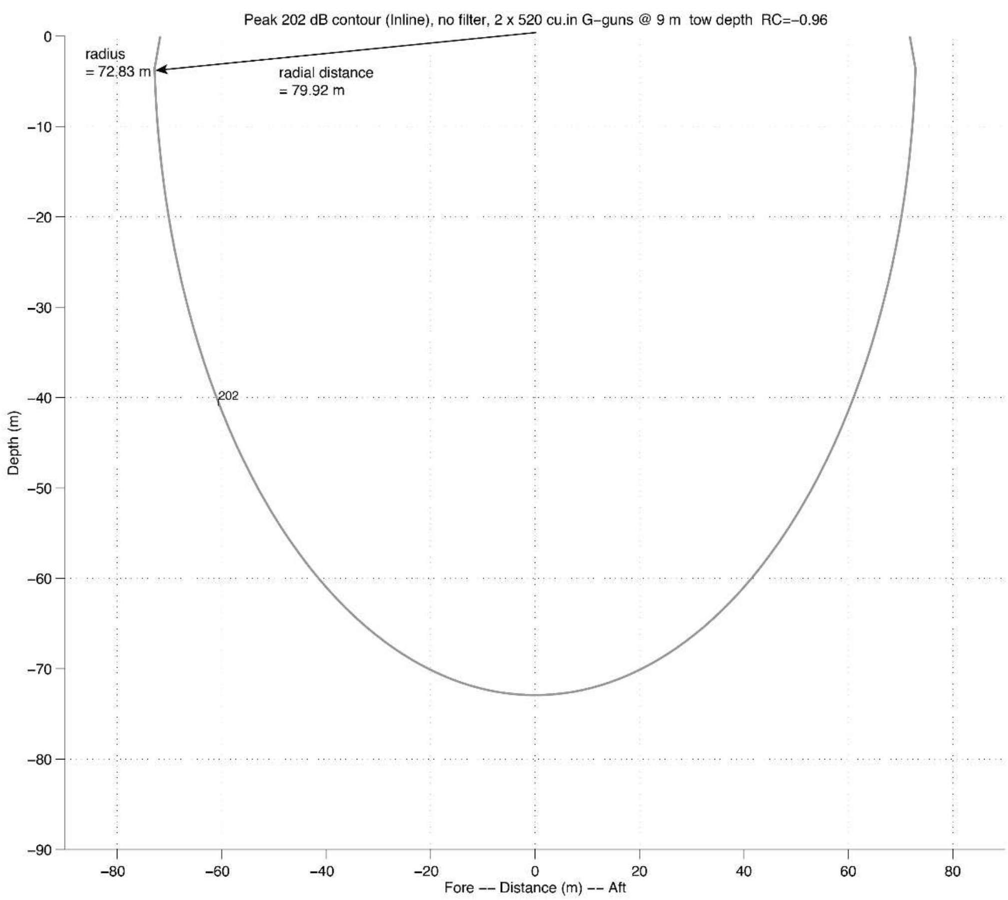

FIGURE A-9. Modeled deep-water received Peak SPL from the 2 G-airgun array at a 9-m tow depth. The plot provides the distance to the 202-dB Peak isopleth.

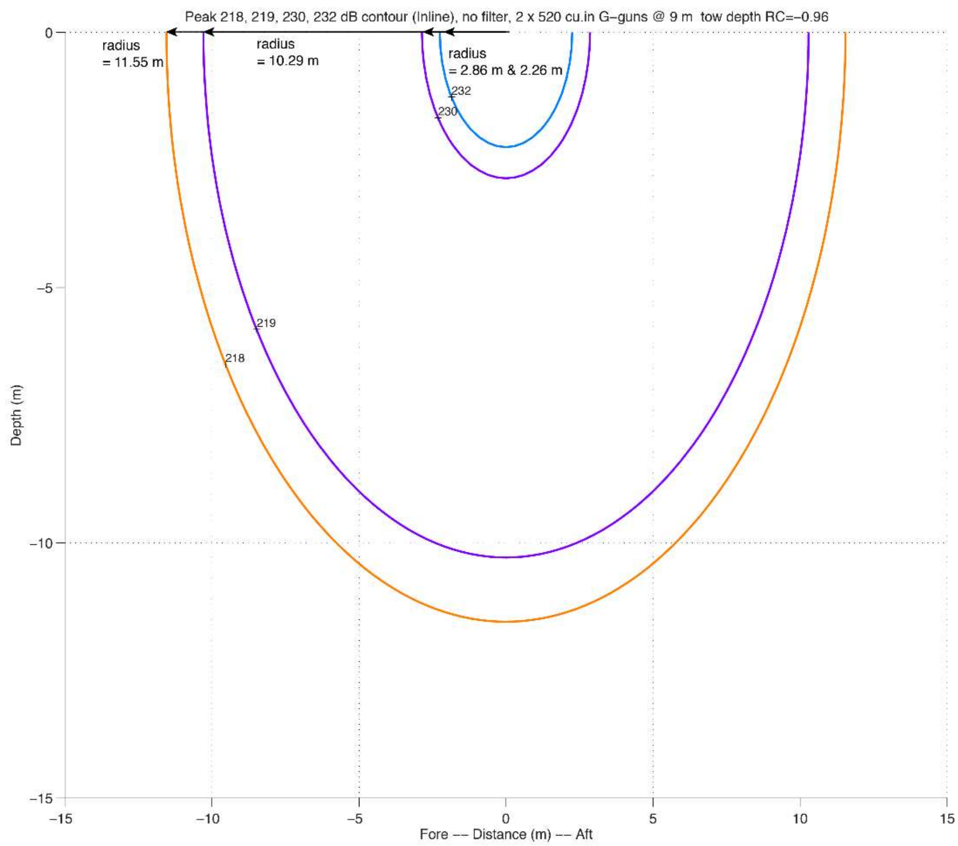

FIGURE A-10. Modeled deep-water received Peak SPL from the 2 G-airgun array at a 9-m tow depth. The plot provides the distances to the 218-, 219-, 230-, and 232-dB Peak isopleths.

TABLE A-5. Results for modified farfield SEL source level modeling for the 6 G-airgun array with and without applying weighting functions to the five marine mammal hearing groups. The modified farfield signature is estimated using the distance from the source array geometrical center to where the SEL_{cum} threshold is the largest. A propagation of 20 log_{10} (Radial distance) is used to estimate the modified farfield SEL.

SEL_{cum} Threshold	183	185	155	185	203
Radial Distance (m) (no weighting	120.9616	95.4383	3127.6	95.4383	10.8078
Modified Farfield SEL	224.6530	224.5945	224.9042	224.5945	223.6747
Radial Distance (m) (with weighting function)	47.2888	N.A.	N.A.	N.A.	N.A.
Adjustment (dB)	-8.1578	N.A.	N.A.	N.A.	N.A.

N.A. means not applicable or not available.

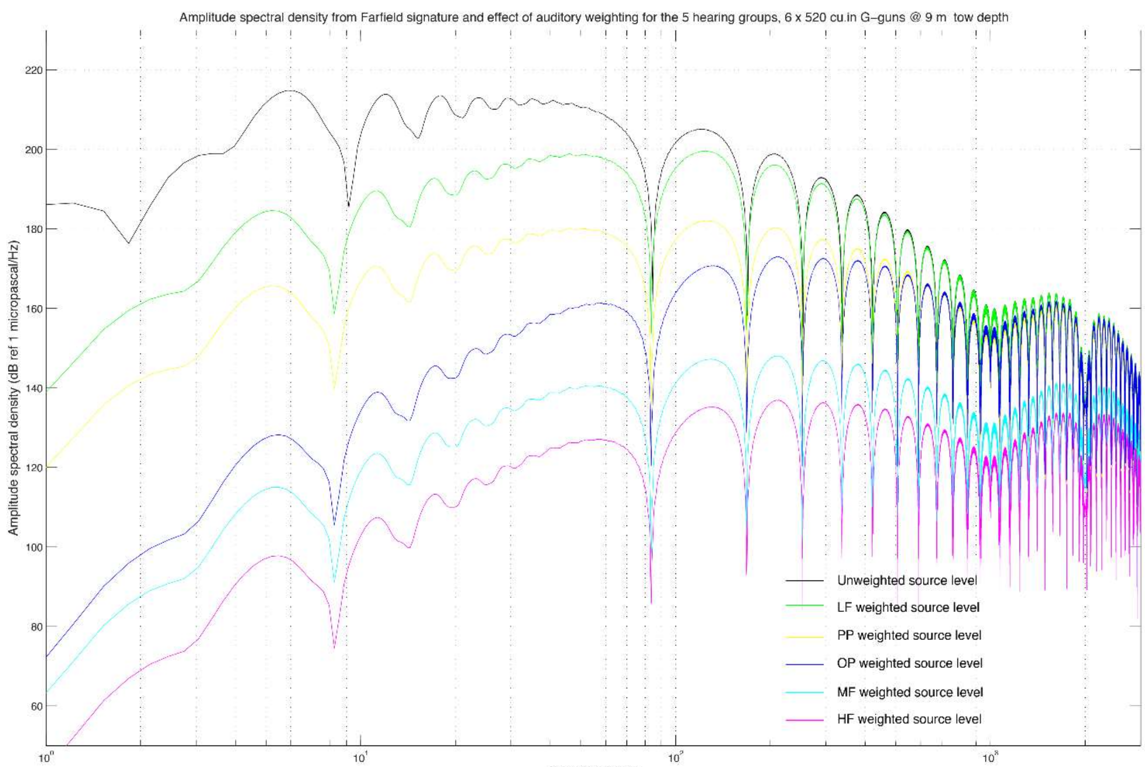

FIGURE A-11. Modeled amplitude spectral density of the 6 G-airgun array farfield signature. Amplitude spectral density before (black) and after (colors) applying the auditory weighting functions for LF, MF, and HF cetaceans, Phocid Pinnipeds (PP), and Otariid Pinnipeds (OP). Modeled spectral levels are 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-6. Results for modified farfield SEL source level modeling for the 6 G-airgun array with weighting function calculations for the SEL_{cum} criteria, as well as resulting isopleths to thresholds for hearing groups.

STEP 1: GENERAL PROJECT INFORMATION

PROJECT TITLE	Bernie Coakley
PROJECT/SOURCE INFORMATION	source : 6 x 520 cu.in G-guns at a 9 m towed depth. Shot inteval is 60s. Source velocity of 4.5 knots
Please include any assumptions	
PROJECT CONTACT	

STEP 2: WEIGHTING FACTOR ADJUSTMENT

Specify if relying on source-specific WFA, alternative weighting/dB adjustment, or if using default value

Weighting Factor Adjustment (kHz)[¥]	NA	Override WFA: Using LDEO modeling

[¥] Broadband: 95% frequency contour percentile (kHz) OR Narrowband: frequency (kHz); For appropriate default WFA: See INTRODUCTION tab

† If a user relies on alternative weighting/dB adjustment rather than relying upon the WFA (source-specific or default), they may override the Adjustment (dB) (row 62), and enter the new value directly. However, they must provide additional support and documentation supporting this modification.

STEP 3: SOURCE-SPECIFIC INFORMATION

NOTE: Choose either F1 OR F2 method to calculate isopleths (not required to fill in sage boxes for both)

NOTE: LDEO modeling relies on Method F2

F2: ALTERNATIVE METHOD† TO CALCULATE PK and SEL_{cum} (SINGLE STRIKE/SHOT/PULSE EQUIVALENT)

SEL_{cum}

Source Velocity (meters/second)	2.315
1/Repetition rate^ (seconds)	60

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

^Time between onset of successive pulses.

Modified farfield SEL	224.653	224.5945	224.9042	224.5945	223.6747
Source Factor	4.86574E+20	4.80064E+20	5.15548E+20	4.80064E+20	3.88435E+20

RESULTANT ISOPLETHS*

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

Hearing Group	Low-Frequency Cetaceans	Mid-Frequency Cetaceans	High-Frequency Cetaceans	Phocid Pinnipeds	Otariid Pinnipeds
SEL_{cum} Threshold	183	185	155	185	203
PTS SEL_{cum} Isopleth to threshold (meters)	**50.6**	**0.0**	**0.0**	**0.4**	**0.0**

WEIGHTING FUNCTION CALCULATIONS

Weighting Function Parameters	Low-Frequency Cetaceans	Mid-Frequency Cetaceans	High-Frequency Cetaceans	Phocid Pinnipeds	Otariid Pinnipeds	
a	1	1.6	1.8	1	2	
b	2	2	2	2	2	
f_1	0.2	8.8	12	1.9	0.94	
f_2	19	110	140	30	25	
C	0.13	1.2	1.36	0.75	0.64	
Adjustment (dB)†	-8.16	-57.42	-66.65	-26.67	-33.34	OVERIDE Using LDEO Modeling

†For LF cetaceans, the adjustment factor (dB) is derived by estimating the radial distance of the 183-dB isopleth without applying the weighting function and a second time with applying the weighting function. Adjustment was derived using a propagation of 20*$\log_{10}$ (Radial distance) and the modified farfield signature. For MF and HF cetaceans and pinnipeds, the difference between weighted–unweighted spectral source levels at each frequency was integrated to calculate adjustment factors (see spectrum levels in Figure A-11).

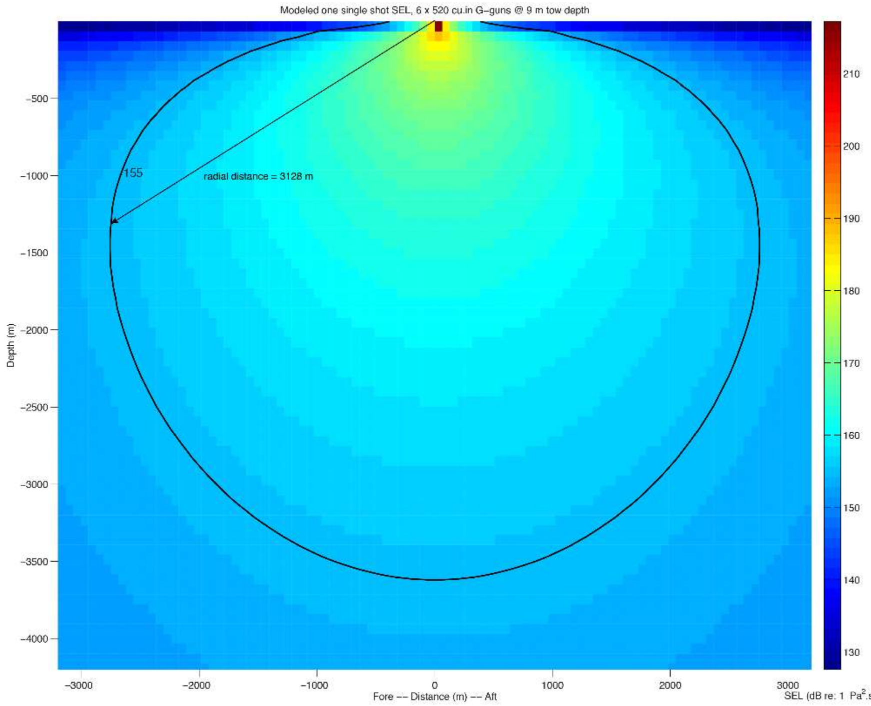

FIGURE A-12. Modeled received sound levels (SELs) in deep water from the 6 G-airgun array. The plot provides the radial distance from the geometrical center of the source array to the 155-dB SEL isopleth.

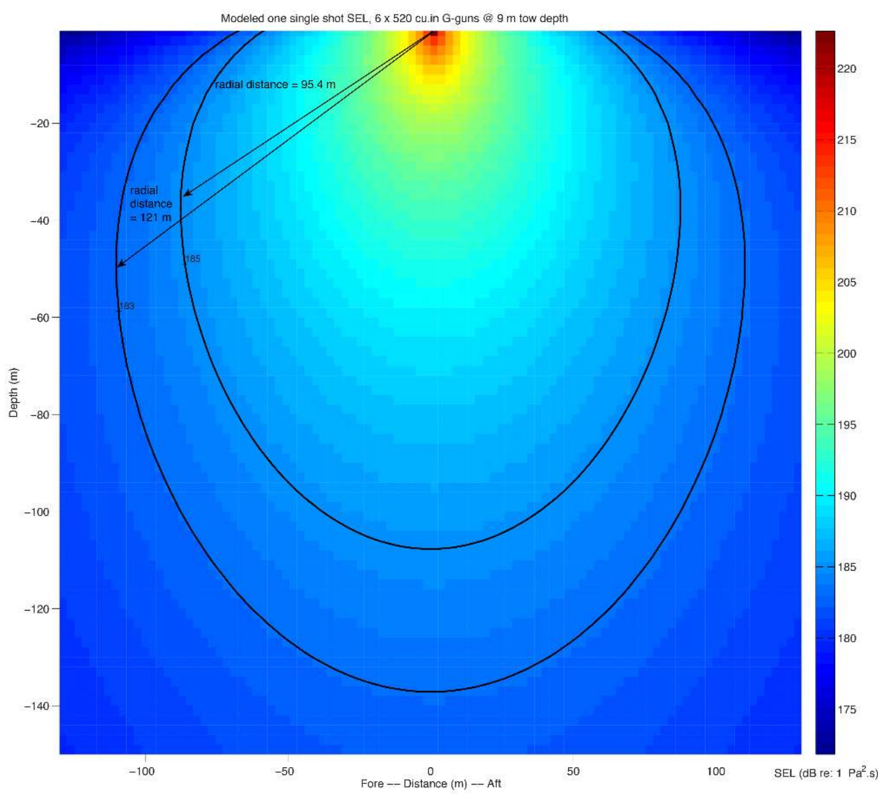

FIGURE A-13. Modeled received sound levels (SELs) in deep water from the 6 G-airgun array. The plot provides the radial distance from the geometrical center of the source array to the 183–185-dB SEL isopleths.

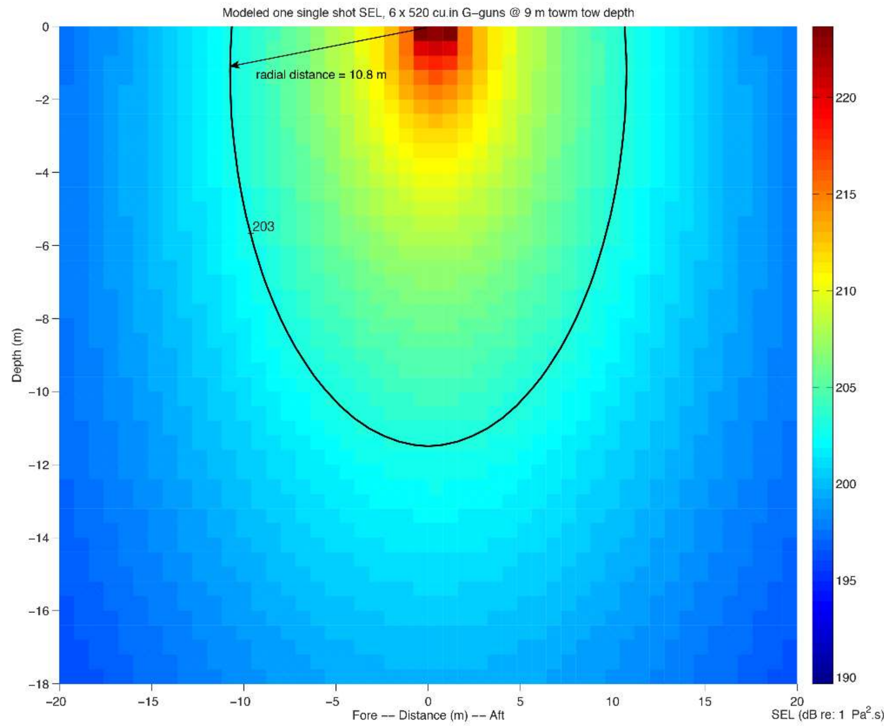

FIGURE A-14. Modeled received sound levels (SELs) in deep water from the 6 G-airgun array. The plot provides the radial distance from the geometrical center of the source array to the 203-dB SEL isopleth.

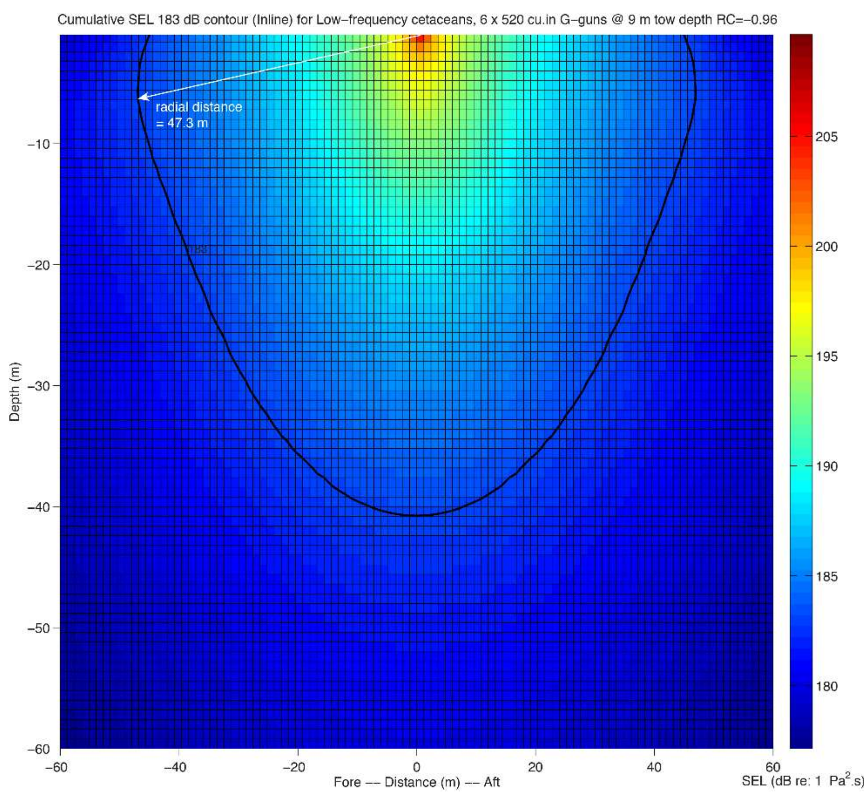

FIGURE A-15. Modeled received sound exposure levels (SELs) from the 6 G-airgun array at a 9-m tow depth, after applying the auditory weighting function for the LF cetaceans hearing group following the NMFS Technical Guidance. The plot provides the radial distance to the 183-dB SEL_{cum} isopleth for one shot.

TABLE A-7. NMFS Level A acoustic thresholds (Peak SPL_{flat}) for impulsive sources for marine mammals and predicted distances to Level A thresholds for various marine mammal hearing groups that could be received from the 6 G-airgun array during the proposed surveys in the Arctic Ocean.

Hearing Group	Low-Frequency Cetaceans	Mid-Frequency Cetaceans	High-Frequency Cetaceans	Phocid Pinnipeds	Otariid Pinnipeds
Peak Threshold	**219**	**230**	**202**	**218**	**232**
Radial Distance to Threshold (m)	29.8	7.2424	214.0959	33.603	5.1478
Modified Farfield Peak SPL	248.4971	247.1977	248.6122	248.5276	246.2324
PTS Peak Isopleth (Radius) to Threshold (m)	29.8	7.2	211.5	33.6	5.1

N.A. means not applicable or not available.

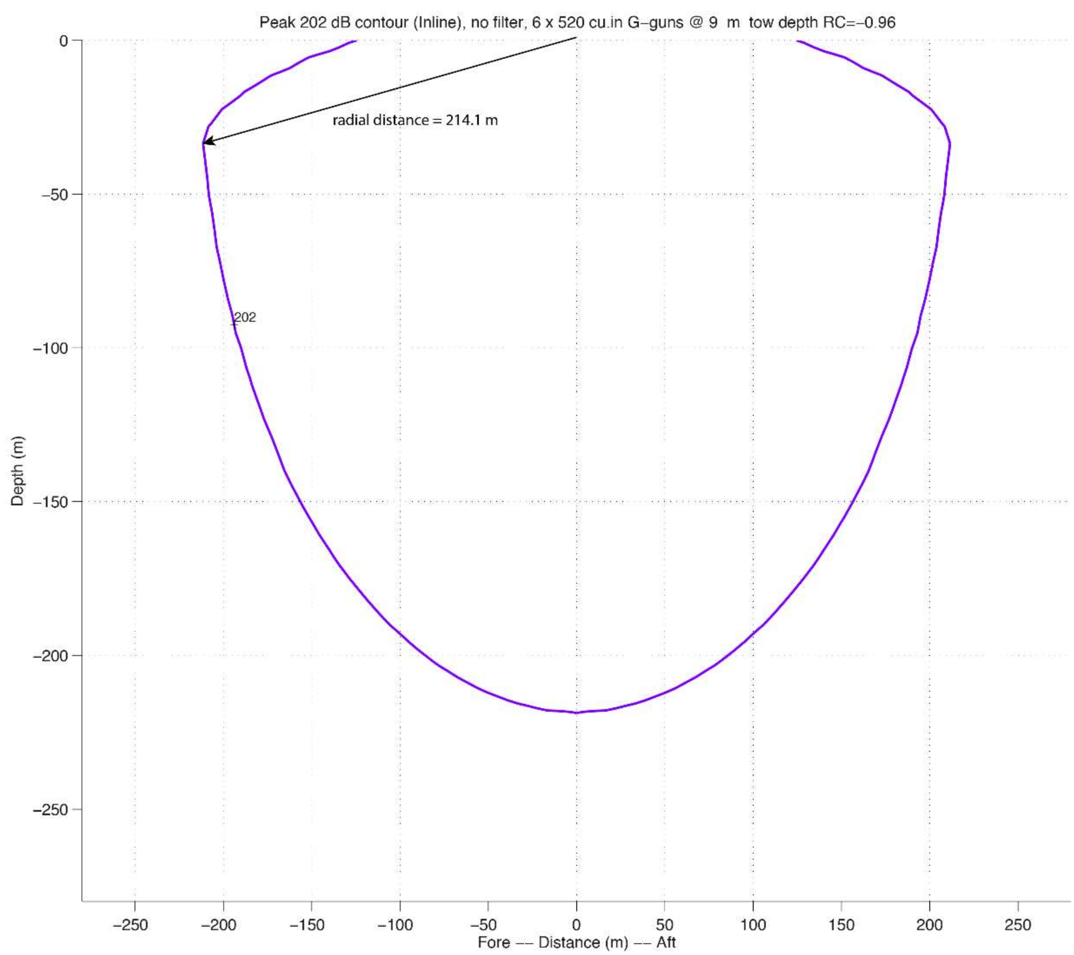

FIGURE A-16. Modeled deep-water received Peak SPL from the 6 G-airgun array at a 9-m tow depth. The plot provides the distance to the 202-dB Peak isopleth.

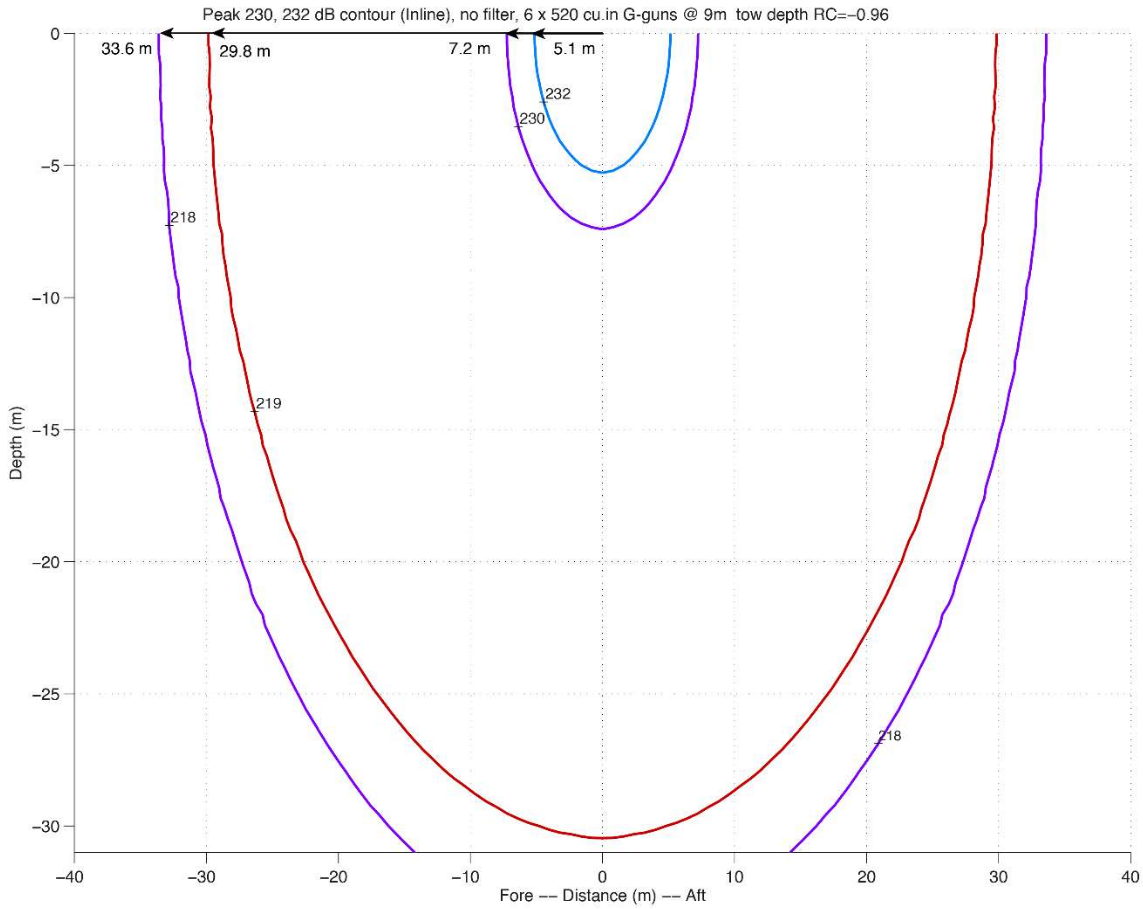

FIGURE A-17 Modeled deep-water received Peak SPL from the 6 G-airgun array at a 9-m tow depth. The plot provides the distances to the 218-, 219-, 230-, and 232-dB Peak isopleths.

Literature Cited

Barton, P., J. Diebold, and S. Gulick. 2006. Balancing mitigation against impact: a case study from the 2005 Chicxulub seismic survey. **Eos Trans. Amer. Geophys. Union** 87(36), Joint Assembly Suppl., Abstr. OS41A-04. 23–26 May, Balitmore, MD.

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

Crone, T.J., M. Tolstoy, and H. Carton. 2014. Estimating shallow water sound power levels and mitigation radii for the R/V *Marcus G. Langseth* using an 8 km long MCS streamer. **Geochem. Geophys. Geosyst.** 15(10):3793-3807.

Crone, T.J., M. Tolstoy, and H. Carton. 2017. Utilizing the R/V *Marcus G. Langseth*'s streamer to measure the acoustic radiation of its seismic source in the shallow waters of New Jersey's continental shelf. PloS ONE 12(8):e0183096. http://doi.org/10.1371/journal.pone.0183096.

Diebold, J.B., M. Tolstoy, P.J. Barton, and S.P. Gulick. 2006. Propagation of exploration seismic sources in shallow water. **Eos Trans. Amer. Geophys. Union** 87(36), Joint Assembly Suppl., Abstr. OS41A-03. 23–26 May, Baltimore, MD.

Diebold, J.B., M. Tolstoy, L. Doermann, S.L. Nooner, S.C. Webb, and T.J. Crone. 2010. R/V *Marcus G. Langseth* seismic source: modeling and calibration. **Geochem. Geophys. Geosyst.** 11(12):Q12012. http://doi.org/10.1029/2010GC003126. 20 p.

Finneran, J.J. 2016. Auditory weighting functions and TTS/PTS exposure functions for marine mammals exposed to underwater noise. Technical Report 3026. SSC Pacific, San Diego, CA.

NMFS. 2016. Technical guidance for assessing the effects of anthropogenic sound on marine mammal hearing: underwater acoustic thresholds for onset of permanent and temporary threshold shifts. U.S. Dept. of Commer., NOAA. 178 p.

NMFS. 2018. 2018 revision to: technical guidance for assessing the effects of anthropogenic sound on marine mammal hearing (version 2.0). Underwater thresholds for onset of permanent and temporary threshold shifts. Office of Protected Resources Nat. Mar. Fish. Serv., Silver Spring, MD. 167 p.

Sivle, L.D., P.H., Kvadsheim, and M.A. Ainslie. 2014. Potential for population-level disturbance by active sonar in herring. **ICES J. Mar. Sci.** 72:558-567.

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

Southall, B.L., J.J. Finneran, C. Reichmuth, P.E. Nachtigall, D.R. Ketten, A.E. Bowles, W.T. Ellison, D.P. Nowacek, and P.L. Tyack. 2019. Marine mammal noise exposure criteria: Updated scientific recommendations for residual hearing effects. **Aquatic Mamm.** 45(2):125-232.

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

APPENDIX B: ENSONIFIED AREAS FOR TAKE CALCULATIONS

APPENDIX B: ENSONIFIED AREAS FOR TAKE CALCULATIONS

Survey Type	Depth Class	Criteria	Ensonified Area (km^2)	Ensonified Area + 25% Increase	Relevant Isopleth (m)
OBS	Deep >1000 m	160 dB	6,172	7,715	4,640
MCS	Deep >1000 m	160 dB	10,256	12,821	1,604
MCS	Intermediate 100-1000 m	160 dB	5,419	6,774	2,406
			21,847	27,309	
OBS	All	LF Cetacean	68.8	86.1	50.6
OBS	All	MF Cetacean	9.8	12.2	7.2
OBS	All	HF Cetacean	287.5	359.4	211.5
OBS	All	Phocid	45.7	57.1	33.6
OBS	All	Otariid	6.9	8.7	5.1
MCS	All	LF Cetacean	154.3	192.9	17.2
MCS	All	MF Cetacean	26.0	32.5	2.9
MCS	All	HF Cetacean	652.1	815.2	72.8
MCS	All	Phocid	104.1	130.1	11.6
MCS	All	Otariid	20.6	25.8	2.3
Total (OBS+MCS)	All	LF Cetacean	223.2	279.0	
Total (OBS+MCS)	All	MF Cetacean	35.8	44.8	
Total (OBS+MCS)	All	HF Cetacean	939.7	1174.6	
Total (OBS+MCS)	All	Phocid	149.8	187.3	
Total (OBS+MCS)	All	Otariid	27.6	34.5	