Request by the University of Texas for an Incidental Harassment Authorization to Allow the Incidental Take of Marine Mammals during Marine Geophysical Surveys in the Northwestern Gulf of Mexico

submitted by

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to

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TABLE OF CONTENTS

LIST OF FIGURES

Page

LIST OF TABLES

Page

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SUMMARY

Researchers from the University of Texas at Austin (UT), with cost-shared funding from the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL), propose to conduct marine geophysical surveys in the Gulf of Mexico (GoM), within Texas state waters, during fall 2023. The proposed seismic surveys would use up to 2 Generator-Injector (GI) airguns, with a total discharge volume of ~210 in^3, in water depths of less than 20 m. The surveys would occur within the Exclusive Economic Zones (EEZ) of the U.S.

Numerous species of marine mammals inhabit the GoM, including the sperm whale and Rice's whale which are listed as ***endangered*** under the U.S. *Endangered Species Act* (ESA) and managed by the National Marine Fisheries Service (NMFS). However, those two ***endangered*** cetaceans, along with the ***threatened*** West Indian manatee, which is managed by the U.S. Fish and Wildlife Service (USFWS), are not likely to be encountered in the proposed shallow-water survey area in the northwestern GoM. Similarly, baleen whales, beaked whales, and *Kogia* spp. are unlikely to be encountered in the shallow waters of the proposed survey area. However, delphinids do occur within the proposed survey area. This request is submitted pursuant to Section 101 (a)(5)(D) of the *Marine Mammal Protection Act* (MMPA), 16 U.S.C. § 1371(a)(5).

The items required to be addressed pursuant to 50 C.F.R. § 216.104, "Submission of Requests", are set forth below. They include descriptions of the specific operations to be conducted, the marine mammals occurring in the survey area, proposed measures to mitigate against any potential injurious effects on marine mammals, and a plan to monitor any behavioral effects of the operations on those marine mammals.

I. OPERATIONS TO BE CONDUCTED

A detailed description of the specific activity or class of activities that can be expected to result in incidental taking of marine mammals.

1.1 Overview of the Activity

The proposed marine seismic surveys using two GI airguns would be used to validate novel dynamic acoustic positioning technology for improving the accuracy in time and space of high-resolution 3-dimensional (HR3D) marine seismic technology. In particular, the seismic data would be used for field validation of monitoring, verification, and account technology for future sub-seabed carbon storage. The proposed surveys would occur within the 222 km^2 survey area (depicted in Fig. 1), located at approximately 28.9–29.1°N, 94.9–95.2°W, within the Exclusive Economic Zone (EEZ) of the U.S. The area of interest is located offshore San Luis Pass, which defines the southern tip of Galveston Island, Texas, and is situated approximately 22 km northeast of Freeport, TX, and approximately 3 km from shore within Texas state waters (Fig. 1). The water depth at the site in some parts is as shallow as 10–12 m and no deeper than 20 m. The seismic surveys could occur anywhere within the survey area and the coordinates noted above. The closest approach to shore would approximately 3.2 km.

The main goal of the seismic surveys proposed by the Principal Investigator (PI) Dr. Tip Meckel is to validate novel dynamic acoustic positioning technology for improving the accuracy in time and space of HR3D seismic datasets, in particular as it pertains to field technology of offshore CCS. UT Gulf Coast Carbon Center (GCCC) designed and built GPS receivers that can be used to accurately position the streamer receivers and the acoustic source via tail buoys. Otherwise, the survey would use conventional seismic methodology, involving one source vessel such as the R/V *Brooks McCAll* (or similar vessel operated by TDI-Brooks), and requiring third-party positioning technology and services at additional project expense.

The source vessel would tow one or two 105 in^3 GI airguns, with a total possible discharge volume of ~210 in^3, at a depth of 3 m. The receiving system would consist of four 25-m solid-state (solid flexible polymer – not gel or oil filled) hydrophone streamers, spaced 10-m apart (i.e., 30-m spread), towed at a 2-m depth. The airguns would fire at a shot interval of ~12.5 m (~5–10 s). As the airgun(s) are towed along the survey lines, the hydrophone streamer would transfer the data to the on-board processing system. Approximately 1704 km of seismic acquisition are proposed. All survey effort would occur in water less than 20 m deep. All planned marine-based geophysical data acquisition activities would be conducted by UT with on-board assistance by the scientists who have proposed the studies. The vessel would be self-contained, and the crew would live aboard the vessel.

1.2 Source Vessel Specifications

R/V *Brooks McCall* has an overall length of 48.5 m, a beam of 12.2 m, and a draft of 3.0 m. The vessel speed during seismic operations would be ~4–5 kts (7.4–9.3 km/h); it has a maximum speed of 11 kts (~20.4 km/h). When R/V *Brooks McCall* tows the airgun(s) and hydrophone streamers, the turning rate of the vessel would be limited.

Vessel Specifications

Owner/Operator:	OMA McCall/TDI Brooks International
Port/Flag:	United States of America /Cameron LA
Date Built:	March 2000
Gross Tonnage:	805 GT
Accommodation Capacity:	32

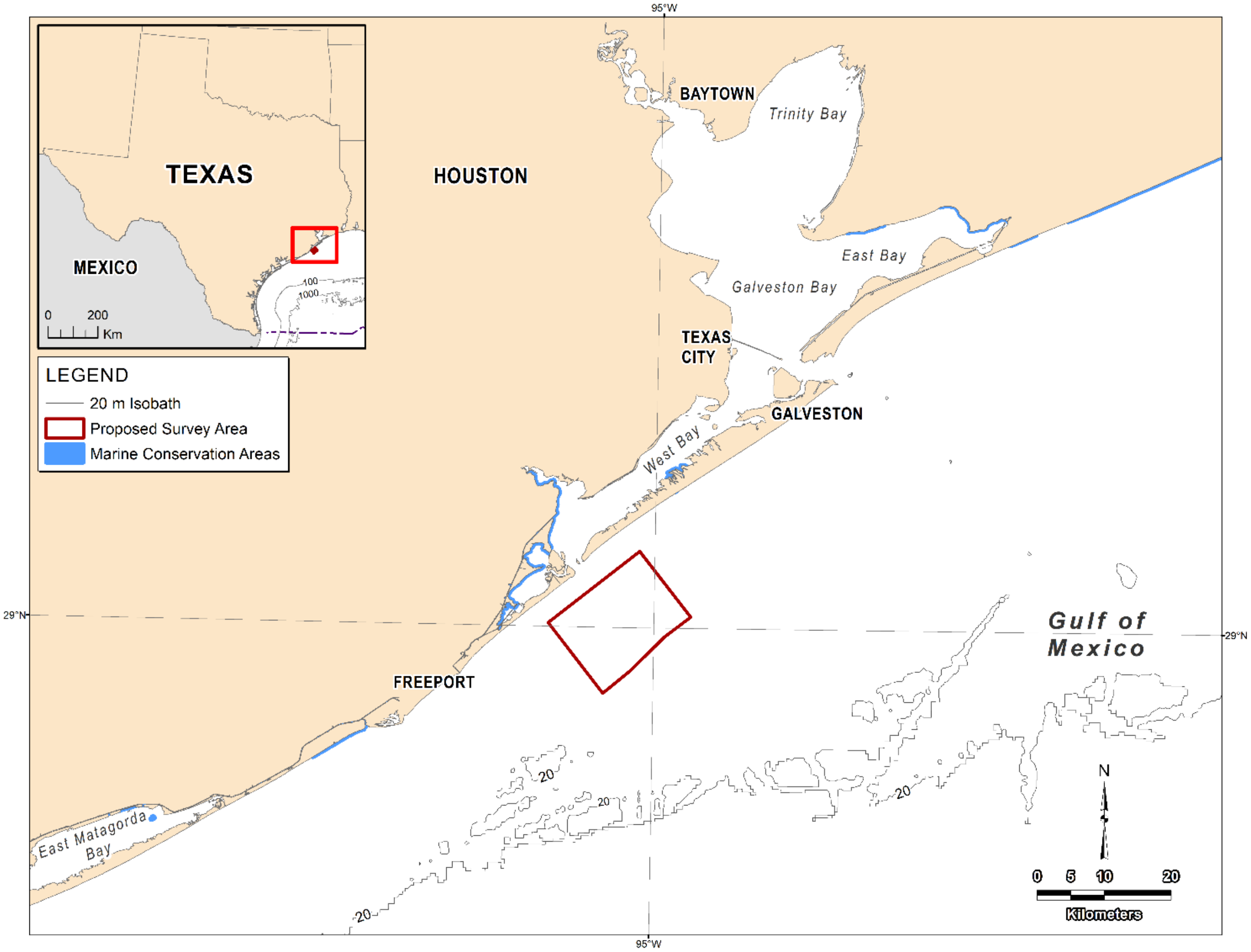

FIGURE 1. Location of the area of interest for the proposed seismic surveys at the offshore portion of Galveston Island at San Luis Pass. Also shown are marine conservation areas. The seismic tracklines could occur anywhere within the survey area.

1.3 Airgun Description

During the seismic surveys, the source vessel would tow one or 2 GI airguns (with a volume of up to 105 in^3 each) and a total discharge volume of ~210 in^3, ~2 m apart, at a depth of ~3 m. The receiving system would consist of four 25-m solid-state (solid flexible polymer – not gel or oil filled) hydrophone streamers, spaced 10-m apart (i.e., 30-m spread), and towed at a 2-m depth. The airguns would fire at a shot interval of ~12.5 m (~5–10 s). The firing pressure of the airguns would be ~2000 psi. During firing, a brief pulse of sound with duration of ~0.1 s would be emitted. The airguns would be silent during the intervening periods. During operations, airgun(s) would be operated 24/7 for multiple days to meet science objectives unless maintenance or mitigation measures warranted.

2-GI Airgun Source Specifications

Energy Source	Two Sercel GI airguns of 105 in^3
Gun Position	Two in-line, ~2 m apart
Tow Depth	3–4 m
Source output (downward)	0-peak: 233.8 dB re 1 µPa · m peak-peak: 239.6 dB re 1 µPa · m
Air discharge volume	~210 in^3
Dominant frequency components	0–188 Hz
Firing pressure:	2000 psi
Pulse duration:	~0.113 s

The source levels for the airgun array was derived from the modeled farfield source signature, which was estimated using the PGS Nucleus software by Lamont-Doherty Earth Observatory (L-DEO) of Columbia University. The nominal downward-directed source level indicated above does not represent the actual sound level that can be measured at any location in the water. Rather, it represents the level that would be found 1 m from a hypothetical point source emitting the same total amount of sound as is emitted by the airgun array. The actual received level at any location in the water near the airguns would not exceed the source level of the strongest individual source. Actual levels experienced by any organism more than 1 m from the airguns would be significantly lower.

A further consideration is that the rms[1] (root mean square) received levels that are used as impact criteria for marine mammals are not directly comparable to the peak (p or 0–p) or peak to peak (p–p) values normally used to characterize source levels of airgun arrays. The measurement units used to describe airgun sources, peak or peak-to-peak decibels, are always higher than the rms decibels referred to in biological literature. A measured received sound pressure level (SPL) of 160 dB re 1 µPa$_{rms}$ in the farfield would typically correspond to ~170 dB re 1 µPa$_{p}$ or 176–178 dB re 1 µPa$_{p\text{-}p}$, as measured for the same pulse received at the same location (Greene 1997; McCauley et al. 1998, 2000). The precise difference between rms and peak or peak-to-peak values depends on the frequency content and duration of the pulse, among other factors. However, the rms level is always lower than the peak or peak-to-peak level for an airgun-type source.

Mitigation zones for the proposed seismic surveys were not derived from the farfield signature but calculated based on modeling by L-DEO for the exclusion zones (EZ) for the Level B (160 dB re 1µPa$_{rms}$) threshold. The background information and methodology for this are provided in Appendix A. L-DEO model results are used to determine the 160-dB$_{rms}$ radius for the airgun source down to a maximum depth of 2000 m (see Appendix A), as animals are generally not anticipated to dive below 2000 m (Costa and Williams 1999). Table 1 shows the distances at which the 160-dB re 1µPa$_{rms}$ sound levels are expected to be received for the 2 GI airguns. The 160-dB level is the behavioral disturbance criterion (Level B) that is used by NMFS to estimate anticipated takes for marine mammals.

This document has been prepared in accordance with the current National Oceanic and Atmospheric Administration (NOAA) acoustic practices, and the monitoring and mitigation procedures are based on best practices noted by Pierson et al. (1998), Weir and Dolman (2007), Nowacek et al. (2013a), Wright (2014), Wright and Cosentino (2015), and Acosta et al. (2017). For other recent low-energy seismic surveys, NMFS required protected species observers (PSOs) to establish and monitor a 100-m exclusion zone (EZ)

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[1] The rms (root mean square) pressure is an average over the pulse duration.

TABLE 1. Predicted distances to behavioral disturbance sound levels ≥160-dB re 1 μPa$_{rms}$ that could be received during the proposed surveys in the northern Gulf of Mexico. The 160-dB criterion applies to all hearing groups of marine mammals (Level B harassment).

Source and Volume	**Max. Tow Depth (m)[1]**	**Water Depth (m)**	**Predicted distances (in m) to the 160-dB Received Sound Level[2]**
Two 105 in^3 GI airguns, 210 in^3 total discharge	4	<100 m	1,750

[1] Maximum tow depth was used for conservative distances. [2] Distance is based on empirically derived measurements in the GoM with scaling applied to account for differences in tow depth.

and an additional 100-m buffer zone beyond the EZ. Enforcement of mitigation zones via shut downs would be implemented as described below. Enforcement of mitigation zones via shut downs would be implemented as described in § XI or as otherwise required by regulators.

1.4 Description of Operations

The proposed marine geophysical surveys would use conventional seismic methodology, requiring third-party positioning technology and services at additional project expense. The seismic surveys would involve one source vessel, such as R/V *Brooks McCall* (or similar vessel operated by TDI-Brooks), which would tow the two GI airguns with a total discharge volume of ~210 in^3 at a depth of 3–4 m. The receiving system would consist of four 25-m solid-state (solid flexible polymer – not gel or oil filled) hydrophone streamers, spaced 10-m apart (i.e., 30-m spread), towed at a 2-m depth. The airguns would fire at a shot interval of approximately 12.5 m (5–10 s). The airguns would be silent during the intervening periods. During operations, airgun(s) would be operated 24/7 for multiple days to meet science objectives unless maintenance or mitigation measures warranted. As the airgun(s) are towed along the survey lines, the hydrophone streamer would transfer the data to the on-board processing system. Approximately 1704 km of seismic acquisition are proposed. All survey effort would occur in water less than 20 m deep.

II. DATES, DURATION, AND REGION OF ACTIVITY

The date(s) and duration of such activity and the specific geographical region where it will occur.

The proposed research would occur within approximately 28.9–29.1°N, 94.9–95.2°W within the U.S. EEZ. Seismic tracklines could occur anywhere within the proposed survey area depicted in Figure 1. The seismic surveys could occur anywhere within the survey area and the coordinates noted above. The area of interest is located offshore San Luis Pass, which defines the southern tip of Galveston Island, Texas, and is situated approximately 22 km northeast of Freeport, TX, and approximately 3 km from shore (Fig. 1). The water depth at the site is less than 20 m deep, and in some parts, it is as shallow as 10–12 m. The seismic surveys could occur anywhere within the proposed survey area and the coordinates noted above. The proposed low-energy surveys with the two GI airguns would be expected to take place during fall 2023 for a period of ~10 days. The source vessel would likely leave out of and return to port in Freeport or Galveston, Texas.

III. SPECIES AND NUMBERS OF MARINE MAMMALS IN AREA

The species and numbers of marine mammals likely to be found within the activity area

Twenty-eight species of cetaceans and one species of manatee are known to occur in the GoM (Jefferson and Schiro 1997; Würsig et al. 2000). Most of these species occur in oceanic waters (>200 m deep), whereas the continental shelf waters (<200 m) are primarily inhabited by bottlenose and Atlantic spotted dolphins (Mullin and Fulling 2004; Mullin 2007). As the proposed survey area in the northwestern GoM occurs in water <20 m deep, species that only occur in deep water of the GoM are unlikely to be encountered and are not discussed further. These include beaked whales, such as Cuvier's beaked whale (*Ziphius cavirostris*), Blainville's beaked whale (*Mesoplodon densirostris*) and Gervais' beaked whales (*M. europaeus*), as well as the ***endangered*** sperm whale (*Physeter macrocephalus*), and *Kogia* spp. It is also unlikely that the ***endangered*** Rice's whale (*Balaneoptera ricei*), fin whale (*B. physalus*), blue whale (*B. musculus*), sei whale (*B. borealis*), or North Atlantic right whale (*Eubalaena glacialis*) would be encountered in the survey area. Most baleen whales are considered rare in the GoM, except for Rice's whale which typically occurs only in the northeastern Gulf; however, one sighting has been reported in water >200 m deep off Texas (Hayes et al. 2021). In addition, non-ESA listed baleen whales, such as humpbacks (*Megaptera novaeangliae*) and minke whales (*B. acutorostrata*) are also unlikely to be encountered during the surveys. Thus, baleen whales are not included in the species descriptions below. In addition, the ***endangered*** Florida stock of the West Indian manatee (*Trichechus manatus*) is also unlikely to occur in the proposed survey area, and pinniped occurrence in the GoM is extralimital; therefore, manatees and pinnipeds are not discussed further. Thus, 14 marine mammal species (all odontocetes) could potentially be encountered in the proposed survey area, although only two species (bottlenose and Atlantic spotted dolphins) are likely to be seen (Table 2).

To avoid redundancy, we have included the required information about the species and (insofar as it is known) numbers of these species in § IV, below.

IV. STATUS, DISTRIBUTION AND SEASONAL DISTRIBUTION OF AFFECTED SPECIES OR STOCKS OF MARINE MAMMALS

A description of the status, distribution, and seasonal distribution (when applicable) of the affected species or stocks of marine mammals likely to be affected by such activities

4.1 Odontocetes

4.1.1 Common Bottlenose Dolphin (*Tursiops truncatus*)

The bottlenose dolphin occurs in tropical, subtropical, and temperate waters throughout the world (Wells and Scott 2018). Although it is more commonly found in coastal and shelf waters, it can also occur in deep offshore waters (Jefferson et al. 2015; Mannocci et al. 2015). In the Northwest Atlantic, these dolphins occur from Nova Scotia to Florida, the GoM, and the Caribbean and southward to Brazil (Würsig et al. 2000). There are two distinct bottlenose dolphin types: a shallow water type mainly found in coastal waters and a deepwater type mainly found in oceanic waters (Duffield et al. 1983; Walker et al. 1999). The nearshore dolphins usually inhabit shallow waters along the continental shelf and upper slope, at depths <200 m (Davis et al. 1998, 2002). Klatsky (2004) noted that offshore dolphins show a preference for water <2186 m deep. As well as inhabiting different areas, these ecotypes differ in their diving abilities (Klatsky 2004) and prey types (Mead and Potter 1995).

TABLE 2. The habitat, occurrence, population sizes, and conservation status of marine mammals that could occur in or near the proposed survey area in the Northwestern Gulf of Mexico.

Species	**Habitat**	**Occurrence in North-western GoM study area**[1]	**Abundance**			**Conservation Status**		
			GoM[2]	**GoM**[3]	**GoM**[3]	**US ESA**[4]	**IUCN**[5]	**CITES**[6]
Bottlenose dolphin	Shelf, coastal and offshore	Common	138,602	63,280[7] 16,407[8] 11,543[9] 20,759[10]	155,453[11]	NL	LC	II
Atlantic spotted dolphin	Mainly coastal	Common	47,488	21,506	6,187[11]	NL	LC	II
Pantropical spotted dolphin	Mainly pelagic	Rare	84,014	37,195	67,225	NL	LC	II
Spinner dolphin	Coastal, pelagic	Rare	13,485	2,991	5,548	NL	LC	II
Striped dolphin	Off the shelf	Rare	4,914	1,817	5,634	NL	LC	II
Clymene dolphin	Pelagic	Rare	11,000	513	4,619	NL	LC	II
Fraser's dolphin	Water >1000 m	Rare	1,665	213	1,665	NL	LC	II
Rough-toothed dolphin	Mostly pelagic	Rare	4,853	unk	4,853	NL	LC	II
Risso's dolphin	Outer shelf, slope, oceanic	Rare	3,137	1,974	1,501	NL	LC	II
Melon-headed whale	Oceanic	Rare	6,733	1,749	6,113	NL	LC	II
Pygmy killer whale	Oceanic	Rare	2,126	613	N.A.	NL	LC	II
False killer whale	Pelagic	Rare	3,204	494	N.A.	NL	NT	II
Killer whale	Widely distributed	Rare	185	267	N.A.	NL	DD	II
Short-finned pilot whale	Mostly pelagic	Rare	1,981[13]	1,321[13]	2,741	NL	LC	II

N.A. = not applicable. unk = unknown.

[1] Occurrence in area at the time of the survey; based on professional opinion and available data.
[2] Roberts et al. (2016a).
[3] From NMFS (2023), based on data from Garrison et al. (2022), except abundance estimates for Fraser's and rough-toothed dolphins, which are from Roberts et al. (2016a).
[4] U.S. Endangered Species Act: NL = not listed.
[5] International Union for the Conservation of Nature Red List of Threatened Species version 2022-1: NT = near threatened; LC = least concern; DD = data deficient.
[6] Convention on International Trade in Endangered Species of Wild Fauna and Flora: Appendix II = not necessarily threatened with extinction but may become so unless trade is closely controlled.
[7] Continental shelf stock.
[8] Eastern coastal stock.
[9] Northern coastal stock.
[10] Western coastal stock.
[11] Shelf population.
[12] Estimate for North Atlantic (Iceland and Faroese Islands; Reyes 1991).
[13] Estimate includes all *Globicephala* sp., although only short-finned pilot whales are present in the GoM.

Both types of bottlenose dolphins are known to occur in the GoM (Walker et al. 1999). The inshore type inhabits shallow lagoons, bays, inlets, and nearshore waters and is the most likely type to be seen in the proposed survey area; the oceanic population occurs in deeper, offshore waters over the continental shelf (Würsig et al. 2000). Vollmer and Rosel (2017) suggested that there may be as many as seven stocks in coastal, shelf, and oceanic waters of the GoM, but NMFS currently recognized only five, including the Northern GoM Continental Shelf, GoM Eastern Coastal, GoM Western Coastal, GoM Northern Coastal, and the Northern GoM Oceanic stocks (Hayes et al. 2022). The Western Coastal stock occurs in water

<20 m deep, and numerous sightings have been made within and near the proposed survey area (Hayes et al. 2022). The Northern GoM Continental Shelf stock occurs in water 20–200 m deep off the coast of Texas (Hayes et al. 2022); it mainly consists of coastal type dolphins but could also include offshore types (Vollmer 2011 *in* Hayes et al. 2022). There are also 31 bay and estuary stocks in the northern GoM (Hayes et al. 2022). The West Bay stock occurs within ~20 km of the survey area, but individuals from this stock are only likely to occur up to 1 km from shore off San Luis Pass (Hayes et al. 2022). The Galveston Bay, East Bay, Trinity Bay stock occurs >20 km away, with most individuals staying within 2 km from shore and up to 5 km out from the Galveston jetties/ship channel (Hayes et al. 2022). These areas in and near West Bay and Galveston Bay, along with numerous other ones along the coast of Texas, have been identified as year-round Biologically Important Areas (BIAs) for resident bottlenose dolphins (LeBresque et al. 2015).

The bottlenose dolphin is the most widespread and common cetacean in coastal waters of the GoM (Würsig et al. 2000; Würsig 2017). Based on Würsig (2017), fall sightings have been made throughout the northern GoM, but primarily on the shelf, whereas during spring and summer surveys, sightings were typically made between the 100- and 1000-m isobaths. During surveys of the eastern GoM by Griffin and Griffin (2003), the bottlenose dolphin was the most common species in water <20 m deep. Baumgartner et al. (2001) reported bottlenose dolphins in the northern GoM on the shallow continental shelf <150 m deep during spring surveys. Fulling et al. (2003) reported a fall density of 10.3 dolphins/100 km^2 for water 20–200 m deep in the northern GoM. For oceanic waters (>200 m) of the northern GoM, Mullin and Fulling (2004) reported a spring density of 0.59 dolphins/100 km^2. Although bottlenose dolphins occur in the GoM year-round, seasonal variation in abundance has been reported for this species (e.g., Hubard et al. 2004). There are several records within and near the proposed survey area in the OBIS database; the records within the survey area are for August and September (OBIS 2022).

4.1.2 Atlantic Spotted Dolphin (*Stenella frontalis*)

The Atlantic spotted dolphin is distributed in tropical and warm temperate waters of the North Atlantic from Brazil to New England and to the coast of Africa (Jefferson et al. 2015). In the western Atlantic, the distribution extends from southern New England, south to the GoM, and the Caribbean to Venezuela (Leatherwood et al. 1976; Perrin et al. 1994a; Rice 1998). There are two forms of Atlantic spotted dolphin—a large, heavily spotted coastal form that is usually found in shelf waters, and a smaller and less-spotted offshore form that occurs in pelagic offshore waters and around oceanic islands (Jefferson et al. 2015).

Atlantic spotted dolphins are common in the GoM (Würsig et al. 2000). They do not typically occur in deep water of the northern GoM, but mainly inhabit shallow waters on the continental shelf inshore of the 250-m isobath (Davis et al. 1998, 2002; Fulling et al. 2003; Würsig 2017; Hayes et al. 2022). Mannocci et al. (2015) also showed occurrence of Atlantic spotted dolphins in deeper waters of the GoM. Numerous sightings have been reported in water <100 m deep off the coast of Texas (Würsig 2017; Hayes et al. 2022). Although Atlantic spotted dolphins prefer shallow-water habitats, they are not common in nearshore waters (Davis et al. 1996).

In the eastern GoM, Atlantic spotted dolphin is the predominant species in water 20–180 m deep (Griffin and Griffin 2003). Similarly, Fulling et al. (2003) noted that the Atlantic spotted dolphin was the most abundant species sighted during a fall survey in water 20–200 m deep, with densities ~8x higher in the northeast (20.1 dolphins/100 km^2) than in the northwestern (2.6 dolphins/100 km^2) GoM. Mullin and Fulling (2004) reported a density of 0.05 dolphins/100 km^2 in water >200 m deep for the northern GoM. Although spotted dolphins occur in the GoM year-round, Griffin and Griffin (2004) noted significant seasonal variations in densities of spotted dolphins on the continental shelf. Griffin and Griffin (2004) and

Griffin et al. (2005) noted that abundance was lower in nearshore waters during the summer, and that densities were higher during the winter. Würsig et al. (2000) noted these dolphins move inshore in the spring and summer, perhaps associated with the arrival of carangid fishes. In the OBIS database, there are numerous records in the northern GoM in water >20 m deep; the closest record to the proposed survey area is located ~70 km to the southeast in water <100 m deep (OBIS 2022).

4.1.3 Pantropical Spotted Dolphin (*Stenella attenuata*)

The pantropical spotted dolphin is distributed worldwide in tropical and some subtropical waters, between ~40°N and 40°S (Jefferson et al. 2015). It is one of the most abundant cetaceans and is found in coastal, shelf, slope, and deep waters (Perrin 2018a). In the Northwest Atlantic, it occurs from North Carolina to the West Indies and down to the Equator (Würsig et al. 2000). In the GoM, it is the most common species of cetacean in deeper water (Davis and Fargion 1996; Würsig et al. 2000), but only rarely occurs over the continental shelf or continental shelf edge (Davis et al. 1998; Waring et al. 2004). Sightings have been made throughout the northern GoM, mainly in water >200 m, during systematic surveys during 1996–2018; one sighting was made in water 100–200 m deep off Florida (Würsig 2017; Hayes et al. 2021). It was the most abundant species during spring surveys in oceanic waters (>200 m) in the northern GoM, with a density of 24 dolphins/100 km^2 (Mullin and Fulling 2004). Fairfield-Walsh et al. (2005) also reported this as the most frequently sighted cetacean in the eastern GoM in waters >200 m deep. It occurs in the GoM year-round (Mullin et al. 2004). The closest record in the OBIS database is ~75 km to the south, in water <100 m deep (OBIS 2022).

4.1.4 Spinner Dolphin (*Stenella longirostris*)

The spinner dolphin is pantropical in distribution, occurring in tropical and sub-tropical waters between 40ºN and 40ºS (Jefferson et al. 2015). In the western North Atlantic, it occurs from South Carolina to Florida, the Caribbean, the GoM, and southward to Venezuela (Würsig et al. 2000). It is generally considered a pelagic species (Perrin 2018b) but can also be found in coastal waters and around oceanic islands (Rice 1998). During systematic surveys of the northern GoM during 1996–2018, sightings were widespread in water deeper than 200 m (Würsig 2017; Hayes et al. 2021). Almost all sightings in the GoM have been made east and southeast of the Mississippi Delta, in areas deeper than 100 m (Würsig et al. 2000; Würsig 2017). Mullin and Fulling (2004) reported a density of 3.15 dolphins/100 km^2 in oceanic waters of the northern GoM. There are several sightings in the OBIS database to the south of the proposed survey area, in water >200 m deep (OBIS 2022).

4.1.5 Striped Dolphin (*Stenella coeruleoalba*)

The striped dolphin has a cosmopolitan distribution in tropical to warm temperate waters from ~50°N to 40°S (Perrin et al. 1994b; Jefferson et al. 2015). It occurs primarily in pelagic waters but has been observed approaching shore where there is deep water close to the coast (Jefferson et al. 2015; Mannocci et al. 2015). In the Northwest Atlantic, it occurs from Nova Scotia to the GoM and south to Brazil (Würsig et al. 2000). A concentration of striped dolphins is thought to exist in the eastern part of the northern GoM, near the DeSoto Canyon just east of the Mississippi Delta (Würsig et al. 2000). Nonetheless, sightings have been made throughout the northern GoM in water >200 m during systematic surveys during 1996–2018 (Würsig 2017). Mullin and Fulling (2004) reported a mean density of 1.71 dolphins/100 km^2 for oceanic waters of the northern GoM. In the OBIS database, there is one record south of the survey area in water >1000 m deep (OBIS 2022).

4.1.6 Clymene Dolphin (*Stenella clymene*)

The Clymene dolphin only occurs in tropical and subtropical waters of the Atlantic Ocean (Jefferson et al. 2015). It inhabits areas where water depths are 700–4500 m or deeper (Fertl et al. 2003). However, there are a few records in water as shallow as 44 m (Fertl et al. 2003). In the western Atlantic, it occurs from New Jersey to Florida, the Caribbean Sea, the GoM, and south to Venezuela and Brazil (Würsig et al. 2000; Fertl et al. 2003). During systematic surveys of the northern GoM during 1996–2018, sightings were made throughout the northwestern GoM, primarily in deep water beyond the 1000-m isobath; no sightings were made in water <100 m deep (Würsig 2017; Hayes et al. 2021). It is widely distributed in the western GoM during spring and the northeast during summer and winter (Würsig et al. 2000). Mullin and Fulling (2004) also noted that this dolphin is primarily sighted in the western GoM in the spring, with an estimated density of 4.56 dolphins/100 km^2 for oceanic waters of the northern GoM. In the OBIS database, there are several records south of the survey area in water >1000 m deep (OBIS 2022).

4.1.7 Risso's Dolphin (*Grampus griseus*)

Risso's dolphin is distributed worldwide in mid-temperate and tropical oceans (Kruse et al. 1999). although it shows a preference for mid-temperate waters of the shelf and slope between 30° and 45° (Jefferson et al. 2014; Hartman 2018). In the western Atlantic, this species is distributed from Newfoundland to Brazil (Kruse et al. 1999). Sightings have been made throughout the northern GoM during systematic surveys during 1996–2018 (Würsig 2017; Hayes et al. 2021). It has mainly been sighted off Florida and in the western GoM off the coast of Texas, and stranding records also exist for Texas and Florida (Würsig 2017; Würsig et al. 2000). Several sightings have been reported for water <200 m deep off the coast of Texas (Würsig 2017; Hayes et al. 2021). Mullin et al. (2004) reported sightings for this species during all seasons in the northern GoM; spring density was reported as 0.57 dolphins/100 km^2 in oceanic waters (>200 m) of the GoM (Mullin and Fulling 2004). In the OBIS database, there are several records south of the survey area in water >200 m deep (OBIS 2022).

4.1.8 Rough-toothed Dolphin (*Steno bredanensis*)

The rough-toothed dolphin is distributed worldwide in tropical and subtropical waters (Jefferson et al. 2015). In the western Atlantic, this species occurs between the southeastern U.S. and southern Brazil, including the GoM (Jefferson et al. 2015). Although it is generally seen in deep, oceanic water (Davis et al. 1998; Jefferson et al. 2015), it also occurs in continental shelf waters of the GoM (Ortega-Ortiz 2002; Fulling et al. 2003). Sightings have been made throughout the northern GoM in water >100 m during systematic surveys of the northern GoM during 1996–2018 (Würsig 2017; Hayes et al. 2021). The fall density for the outer continental shelf waters (20–200 m deep) of the northern GoM was estimated at 0.5 dolphins/100 km^2 (Fulling et al. 2003), whereas that for oceanic waters in spring was estimated at 0.26 dolphins/100 km^2 (Mullin and Fulling 2004). Rough-toothed dolphins are thought to occur year-round in the GoM (Würsig et al. 2000; Mullin et al. 2004). Strandings are known for Texas and Florida (Würsig et al. 2000). In the OBIS database, there are several records south of the survey area in water >100 m deep (OBIS 2021).

4.1.9 Fraser's Dolphin (*Lagenodelphis hosei*)

Fraser's dolphin is a tropical oceanic species generally distributed between 30°N and 30°S that generally inhabits deeper, offshore water (Dolar 2018). It ranges from the GoM to Uruguay in the western Atlantic (Rice 1998). Fraser's dolphin has been sighted on occasion in the northern GoM (Jefferson and Schiro 1997), including in water deeper than 100 m during systematic surveys (Würsig 2017; Hayes et al. 2021). A density of 0.19 dolphins/100 km^2 was estimated for oceanic waters of the northern GoM (Mullin and Fulling 2004). In the OBIS database, there are no records in shelf waters off Texas (OBIS 2022).

4.1.10 Killer Whale (*Orcinus orca*)

The killer whale is cosmopolitan and globally abundant; it has been observed in all oceans of the world (Ford 2018). It is very common in temperate waters but also occurs in tropical waters (Heyning and Dahlheim 1988). High densities of this species occur at high latitudes, especially in areas where prey is abundant. The greatest abundance is thought to occur within 800 km of major continents (Mitchell 1975). In the Northwest Atlantic, killer whales occur from the polar pack ice to Florida and the GoM (Würsig et al. 2000). It is unknown whether killer whales in the GoM are a separate stock or from the North Atlantic population (Würsig 2017).

Killer whales appear to prefer coastal areas but are also known to occur in deep water (Dahlheim and Heyning 1999). In the GoM, killer whales are occasionally seen, with most sightings occurring in waters 200–2000 m deep southwest of the Mississippi Delta (Würsig 2017; Würsig et al. 2000; Hayes et al. 2021). No sightings were reported for water <100 m deep (Würsig 2017). Mullin and Fulling (2004) reported five sightings in the northwestern GoM during the spring and a density of 0.03 animals/100 km^2 for oceanic waters of the northern GoM. There have also been summer reports of killer whales off Texas near the 200-m isobath (Würsig et al. 2000). In the OBIS database, there are no records in shelf waters off Texas (OBIS 2022).

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

The short-finned pilot whale is found in tropical and warm temperate waters, and the long-finned pilot whale (*G. melas*) is distributed antitropically in cold temperate waters (Olson 2018). Short-finned pilot whale distribution does not generally range south of 40°S (Jefferson et al. 2015). In the western North Atlantic, short-finned pilot whales occur from Virginia to northern South America, including the Caribbean and GoM (Würsig et al. 2000). The ranges of the two species show little overlap, and only the short-finned pilot whale is expected to occur in the GoM (Olson 2018). The short-finned pilot whale typically occurs in deep water at the edge of the continental shelf and over deep submarine canyons (Davis et al. 1998; Mannocci et al. 2015).

Short-finned pilot whales are known to strand frequently in the GoM and are likely to occur there year-round (Würsig et al. 2000). In the northern GoM, it is most commonly seen in the central and western areas in waters 200–1000 m deep, i.e., along the continental slope (Würsig 2017; Würsig et al. 2000; Hayes et al. 2021). No sightings were reported for waters <100 m deep (Würsig 2017). Mullin and Fulling (2004) noted that during a spring survey in the northern GoM, short-finned pilot whales were primarily seen west of Mobile Bay, AL (~88ºW); they reported a mean density of 0.63 *Globicephala* spp./100 km^2 for oceanic waters >200 m deep. In the OBIS database, there are several records south of the survey area in water >200 m deep (OBIS 2022).

4.1.12 False Killer Whale (*Pseudorca crassidens*)

The false killer whale is found worldwide in tropical and temperate waters, generally between 50ºN and 50ºS (Odell and McClune 1999). It is widely distributed but is not abundant anywhere (Carwardine 1995). It generally inhabits deep, offshore waters, but sometimes is found over the continental shelf and occasionally moves into very shallow water (Jefferson et al. 2015; Baird 2018b). It is gregarious and forms strong social bonds, as is evident from its propensity to strand en masse (Baird 2018b). In the Northwest Atlantic, it occurs from Maryland to the GoM and the Caribbean (Würsig et al. 2000).

In the GoM, most false killer whales have been seen in the northeastern region (Mullin and Hoggard 2000; Würsig 2017) in water 200–2000 m deep (Würsig 2017; Würsig et al. 2000; Hayes et al. 2021). During systematic surveys of the northern GoM during 1996–2001 and 2003–2004, sightings were primarily beyond the 1000-m isobath (Würsig 2017). Mullin and Fulling (2004) reported a spring density of 0.27 whales/100 km^2 in the oceanic waters of the northern GoM. Strandings have also been reported for the GoM, with records for Texas, Florida, Louisiana (Würsig et al. 2000). In the OBIS database, there is one record southwest of the survey area in water >200 m deep (OBIS 2022).

4.1.13 Pgymy Killer Whale (*Feresa attenuata*)

The pygmy killer whale has a worldwide distribution in tropical and subtropical waters, generally not ranging south of 35°S (Jefferson et al. 2015). It is known to inhabit the warm waters of the Indian, Pacific, and Atlantic oceans (Jefferson et al. 2015). In the Northwest Atlantic, it occurs from the Carolinas to Texas and the West Indies, and the GoM (Würsig et al. 2000). It is found in nearshore areas where the water is deep and in offshore waters (Jefferson et al. 2015). Pygmy killer whales are thought to occur in the GoM year-round (Würsig et al. 2000). Sightings have been made throughout the northern region of the GoM, in water >200 m during systematic surveys during 1996–2018 (Würsig 2017; Hayes et al. 2021). A spring density of 0.11 whales/100 km^2 has was reported for oceanic waters (>200 m) of the northern GoM (Mullin and Fulling 2004). Strandings have been reported from Florida to Texas, with most strandings occurring in the winter (Würsig et al. 2000). In the OBIS database, there are several records south of the survey area in water >200 m deep (OBIS 2022).

4.1.14 Melon-headed Whale (*Peponocephala electra*)

The melon-headed whale is an oceanic species found worldwide in tropical and subtropical waters from ~40°N to 35°S (Jefferson et al. 2015). It occurs most often in deep offshore waters and occasionally in nearshore areas where the water is deep (Jefferson et al. 2015). In the western Atlantic, its range extends from the GoM to southern Brazil (Rice 1998). In the GoM, melon-headed whales have been sighted in the northwest from Texas to Mississippi (Würsig et al. 2000; Würsig 2017), typically in waters >200 m deep and away from the continental shelf (Mullin et al. 1994; Würsig 2017; Würsig et al. 2000; Hayes et al. 2021). No sightings were reported for waters <100 m deep (Würsig 2017). Mullin and Fulling (2004) reported three sightings primarily west of Mobile Bay, AL, during spring surveys, and a density of 0.91 whales/100 km^2 for the northern GoM. Strandings have been reported for Texas and Louisiana (Würsig et al. 2000). In the OBIS database, there are several records southwest of the survey area in water >1000 m deep (OBIS 2022).

V. TYPE OF INCIDENTAL TAKE AUTHORIZATION REQUESTED

The type of incidental taking authorization that is being requested (i.e., takes by harassment only, takes by harassment, injury and/or death), and the method of incidental taking.

UT requests an IHA pursuant to Section 101 (a)(5)(D) of the MMPA for incidental take by harassment during its planned seismic surveys in the northwestern GoM during fall 2023. The operations outlined in § I have the potential to take marine mammals by harassment. Sounds would be generated by the airguns used during the surveys and by general vessel operations. “Takes” by harassment would potentially result when marine mammals near the activity are exposed to the pulsed sounds, such as those generated by the airguns. The effects would depend on the species of marine mammal, the behavior of the animal at the time of reception of the stimulus, as well as the distance and received level of the sound (see § VII). Disturbance reactions are likely amongst some of the marine mammals near the tracklines of the source vessel.

At most, effects on marine mammals would be anticipated as falling within the MMPA definition of "Level B Harassment" for those species managed by NMFS. Although Level A takes are not requested and will likely not be issued, the predicted distances to the Level A threshold distances for two GI airguns were previously determined by L-DEO for a seismic survey in the Ross Sea (LGL Ltd 2022).

VI. NUMBERS OF MARINE MAMMALS THAT COULD BE TAKEN

By age, sex, and reproductive condition (if possible), the number of marine mammals (by species) that may be taken by each type of taking identified in [section V], and the number of times such takings by each type of taking are likely to occur.

The material for § VI and § VII has been combined and presented in reverse order to minimize duplication between sections.

VII. ANTICIPATED IMPACT ON SPECIES OR STOCKS

The anticipated impact of the activity upon the species or stock of marine mammal.

The material for § VI and § VII has been combined and presented in reverse order to minimize duplication between sections.

First, we summarize the potential impacts on marine mammals of airgun operations, as called for in § VII. The material in this section includes a summary of the expected potential effects (or lack thereof) of airgun sounds on marine mammals, including reference to recent literature. A comprehensive review of the relevant background information appears in the 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, referred to herein as the NSF and USGS PEIS (NFS and USGS 2011); relevant background information on the hearing abilities of marine mammals can also be found in that PEIS.

Then, we estimate the numbers of marine mammals that could be affected by the proposed surveys in the GoM. As called for in § VI, this section includes a description of the rationale for the estimates of the potential numbers of harassment "takes" during the planned surveys.

7.1 Summary of Potential Effects of Airgun Sounds

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 2017). In some cases, a behavioral response to a sound can reduce the overall exposure to that sound (e.g., Finneran et al. 2015; Wensveen et al. 2015).

Permanent hearing impairment (PTS), in the unlikely event that it occurred, would constitute injury (Southall et al. 2007; Le Prell 2012). Physical damage to a mammal's hearing apparatus can occur if it is exposed to sound impulses that have very high peak pressures, especially if the impulses have very short rise times (e.g., Morell et al. 2017). However, the impulsive nature of sound is range-dependent (Hastie et al. 2019; Martin et al. 2020) and may become less harmful over distance from the source (Hastie et al. 2019). TTS is not considered an injury (Southall et al. 2007; Le Prell 2012). Rather, the onset of TTS has been considered an indicator that, if the animal is exposed to higher levels of that sound, physical damage is ultimately a possibility. Nonetheless, research has shown that sound exposure can cause cochlear neural degeneration, even when threshold shifts, and hair cell damage are reversible (Kujawa and Liberman 2009; Liberman et al. 2016). These findings have raised some doubts as to whether TTS should continue to be considered a non-injurious effect (Weilgart 2014; Tougaard et al. 2015, 2016; Houser 2021). Although the possibility cannot be entirely excluded, it would be unlikely that the proposed surveys would result in any cases of temporary or permanent hearing impairment, or any significant non-auditory physical or physiological effects. If marine mammals were encountered during an active survey, some behavioral disturbance could result, but this would be localized and short-term.

7.1.1 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.

7.1.2 Masking

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

Some baleen and toothed whales are known to continue calling in the presence of seismic pulses, and their calls usually can be heard between the pulses (e.g., Nieukirk et al. 2012; Thode et al. 2012; Bröker et al. 2013; Sciacca et al. 2016). Cerchio et al. (2014) suggested that the breeding display of humpback whales off Angola could be disrupted by seismic sounds, as singing activity declined with increasing received levels. In addition, some cetaceans are known to change their calling rates, shift their peak frequencies, or otherwise modify their vocal behavior in response to airgun sounds (e.g., Di Iorio and Clark 2010; Castellote et al. 2012; Blackwell et al. 2013, 2015; Thode et al. 2020; Fernandez-Betelu et al. 2021). The hearing systems of baleen whales are undoubtedly more sensitive to low-frequency sounds than are the ears of the small odontocetes that have been studied directly (e.g., MacGillivray et al. 2014). The sounds important to small odontocetes are predominantly at much higher frequencies than are the dominant components of airgun sounds, thus limiting the potential for masking. In general, masking effects of seismic pulses are expected to be minor, given the normally intermittent nature of seismic pulses.

7.1.3 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; this has proven to be complicated by numerous factors including variability in responses between individuals (e.g., New et al. 2013b; King et al. 2015; Costa et al. 2016a,b; Ellison et al. 2016; Harwood et al. 2016; Nowacek et al. 2016; Farmer et al. 2017; Dunlop et al. 2021; Gallagher et al. 2021; McHuron et al. 2021; Mortensen et al. 2021).

Given the many uncertainties in predicting the quantity and types of impacts of noise on marine mammals, it is common practice to estimate how many marine mammals would be present within a particular distance of industrial activities and/or exposed to a particular level of industrial sound. In most cases, this approach likely overestimates the numbers of marine mammals that would be affected in some biologically important manner.

The sound criteria used to estimate how many marine mammals could be disturbed to some biologically important degree by a seismic program are based primarily on behavioral observations of a few species; detailed studies have been done on humpback, gray, bowhead, and sperm whales. Less detailed data are available for some other species of baleen whales and small toothed whales, but for many species, there are no data on responses to marine seismic surveys; many data gaps remain where exposure criteria are concerned (Southall 2021).

Baleen Whales.—Baleen whales generally tend to avoid operating airguns, but avoidance radii are quite variable. Whales are often reported to show no overt reactions to pulses from large arrays of airguns at distances beyond a few kilometers, even though the airgun pulses remain well above ambient noise levels out to much longer distances. However, baleen whales exposed to strong noise pulses from airguns often react by deviating from their normal migration route and/or interrupting their feeding and moving away. In the cases of migrating gray and bowhead whales, the observed changes in behavior appeared to be of little or no biological consequence to the animals. They simply avoided the sound source by displacing their migration route to varying degrees, but within the natural boundaries of the migration corridors (Malme et al. 1984; Malme and Miles 1985; Richardson et al. 1995). Kavanagh et al. (2019) analyzed more than 8000 hr of cetacean survey data in the northeastern Atlantic Ocean to determine the effects of the seismic surveys on cetaceans. They found that sighting rates of baleen whales were significantly lower during seismic surveys compared with control surveys.

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

Dunlop et al. (2015) reported that migrating humpback whales in Australia responded to a vessel operating a 20 in^3 airgun by decreasing their dive time and speed of southward migration; however, the same responses were obtained during control trials without an active airgun, suggesting that humpbacks responded to the source vessel rather than the airgun. A ramp up was not superior to triggering humpbacks to move away from the vessel compared with a constant source at a higher level of 140 in^3, although an increase in distance from the airgun(s) was noted for both sources (Dunlop et al. 2016a). Avoidance was also shown when no airguns were operational, indicating that the presence of the vessel itself had an effect on the response (Dunlop et al. 2016a,b, 2020). Overall, the results showed that humpbacks were more likely to avoid active small airgun sources (20 and 140 in^3) within 3 km and received levels of at least 140 dB re 1 $\mu\text{Pa}^2 \cdot \text{s}$ (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 $\mu\text{Pa}^2 \cdot \text{s}$ (Dunlop et al. 2017b, 2018). These results are consistent with earlier studies (e.g., McCauley et al. 2000). Dunlop et al. (2020) found that humpback whales reduce their social interactions at greater distances and lower received levels than regulated by current mitigation practices.

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

Matthews and Parks (2021) summarized the known responses of *right whales* to sounds; however, there are no data on reactions of right whales to seismic surveys. However, Rolland et al. (2012) suggested that ship noise causes increased stress in right whales; they showed that baseline levels of stress-related faecal hormone metabolites decreased in North Atlantic right whales with a 6-dB decrease in underwater noise from vessels. Wright et al. (2011), Atkinson et al. (2015), Houser et al. (2016), and Lyamin et al. (2016) also reported that sound could be a potential source of stress for marine mammals.

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

Bowhead whale calls detected in the presence and absence of airgun sounds have been studied extensively in the Beaufort Sea. Bowheads continue to produce calls of the usual types when exposed to airgun sounds on their summering grounds, although numbers of calls detected are significantly lower in the presence than in the absence of airgun pulses (Blackwell et al. 2013, 2015). Blackwell et al. (2013) reported that calling rates in 2007 declined significantly where received SPLs from airgun sounds were 116–129 dB re 1 µPa; at SPLs <108 dB re 1 µPa, calling rates were not affected. When data for 2007–2010 were analyzed, Blackwell et al. (2015) reported an initial increase in calling rates when airgun pulses became detectable; however, calling rates leveled off at a received $\text{CSEL}_{10\text{-min}}$ (cumulative SEL over a 10-min period) of ~94 dB re 1 $\mu\text{Pa}^2 \cdot \text{s}$, decreased at $\text{CSEL}_{10\text{-min}}$ >127 dB re 1 $\mu\text{Pa}^2 \cdot \text{s}$, and whales were nearly silent at $\text{CSEL}_{10\text{-min}}$ >160 dB re 1 $\mu\text{Pa}^2 \cdot \text{s}$. Thode et al. (2020) reported similar changes in bowhead whale vocalizations when data were analyzed for the period 2008–2014. Thus, bowhead whales in the Beaufort Sea apparently decreased their calling rates in response to seismic operations, although movement out of the area could also have contributed to the lower call detection rate (Blackwell et al. 2013, 2015).

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

There was no indication that *western gray whales* exposed to seismic sound were displaced from their overall feeding grounds near Sakhalin Island during seismic programs in 1997 (Würsig et al. 1999) and in 2001 (Johnson et al. 2007; Meier et al. 2007; Yazvenko et al. 2007a). However, there were indications of subtle behavioral effects among whales that remained in the areas exposed to airgun sounds (Würsig et al. 1999; Gailey et al. 2007; Weller et al. 2006a) and localized redistribution of some individuals within the nearshore feeding ground so as to avoid close approaches by the seismic vessel (Weller et al. 2002, 2006b; Yazvenko et al. 2007a). Despite the evidence of subtle changes in some quantitative measures of behavior and local redistribution of some individuals, there was no apparent change in the frequency of feeding, as evident from mud plumes visible at the surface (Yazvenko et al. 2007b). Similarly, no large changes in gray whale movement, respiration, or distribution patterns were observed during the seismic programs conducted in 2010 (Bröker et al. 2015; Gailey et al. 2016). Although sighting distances of gray whales from shore increased slightly during a 2-week seismic survey, this result was not significant (Muir et al. 2015). However, there may have been a possible localized avoidance response to high sound levels in the area (Muir et al. 2016). The lack of strong avoidance or other strong responses during the 2001 and 2010 programs was presumably in part a result of the comprehensive combination of real-time monitoring and mitigation measures designed to avoid exposing western gray whales to received SPLs above ~163 dB re 1 µPa$_{rms}$ (Johnson et al. 2007; Nowacek et al. 2012, 2013b). In contrast, despite rigorous monitoring and mitigation measures during multiple seismic surveys in 2015 (Aerts et al. 2022; Rutenko et al. 2022), data collected during a program with multiple seismic surveys in 2015 showed short-term and long-term displacement of animals from the feeding area, at least short-term behavioral changes, and responses to lower sound levels than expected (Gailey et al. 2017, 2022a,b; Sychenko et al. 2017). However, stochastic dynamic programming (SDP) model predictions showed similar reproductive success and habitat use by gray whales with or without exposure to airgun sounds during the 2015 program (Schwarz et al. 2022).

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

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

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

Data on short-term reactions by cetaceans to impulsive noises are not necessarily indicative of long-term or biologically significant effects. It is not known whether impulsive sounds affect reproductive rate or distribution and habitat use in subsequent days or years. However, gray whales have continued to migrate annually along the west coast of North America with substantial increases in the population over recent years, despite intermittent seismic exploration (and much ship traffic) in that area for decades. The western Pacific gray whale population continued to feed off Sakhalin Island every summer, despite seismic surveys in the region. In addition, bowhead whales have continued to travel to the eastern Beaufort Sea each summer, and their numbers have increased notably, despite seismic exploration in their summer and autumn range for many years. Pirotta et al. (2018) used a dynamic state model of behavior and physiology to assess the consequences of disturbance (e.g., seismic surveys) on whales (in this case, blue whales). They found that the impact of localized, acute disturbance (e.g., seismic surveys) depended on the whale's behavioral response, with whales that remained in the affected area having a greater risk of reduced reproductive success than whales that avoided the disturbance. Chronic, but weaker disturbance (e.g., vessel traffic) appeared to have less effect on reproductive success.

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

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

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

Preliminary findings of a monitoring study of *narwhals* in Melville Bay, Greenland, (summer and fall 2012) showed no short-term effects of seismic survey activity on narwhal distribution, abundance, migration timing, and feeding habits (Heide-Jørgensen et al. 2013a). In addition, there were no reported effects on narwhal hunting. These findings do not seemingly support a suggestion by Heide-Jørgensen et al. (2013b) that seismic surveys in Baffin Bay may have delayed the migration timing of narwhals, thereby increasing the risk of narwhals to ice entrapment. However, Heide-Jørgensen et al. (2021) did report avoidance reaction at distances >11 km from an active seismic vessel, as well as an increase in travel speed and changes in direction at distances up to 24 km from a seismic source. No long-term effects were reported. Tervo et al. (2021) reported that narwhal buzzing rates decreased in response to concurrent ship noise and airgun pulses (being 50% at 12 km from ship), and that the whales discontinued to forage at 7–8 km from the vessel, and that exposure effects could still be detected >40 km from the vessel.

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

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

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

The limited available data suggest that *harbor porpoises* show stronger avoidance of seismic operations than do Dall's porpoises. The apparent tendency for greater responsiveness in the harbor porpoise is consistent with its relative responsiveness to boat traffic and some other acoustic sources (Richardson et al. 1995; Southall et al. 2007). Based on data collected by observers on seismic vessels off the U.K. from 1994–2010, detection rates of harbor porpoises were significantly higher when airguns were silent vs. when large or small arrays were operating (Stone 2015). In addition, harbor porpoises were seen farther away from the array when it was operating vs. silent, and were most often seen traveling away from the airgun array when it was in operation (Stone 2015). Thompson et al. (2013) reported decreased densities and reduced acoustic detections of harbor porpoise in response to a seismic survey in Moray Firth, Scotland, at ranges of 5–10 km (SPLs of 165–172 dB re 1 μPa, SELs of 145–151 dB $\mu Pa^2 \cdot s$). For the same survey, Pirotta et al. (2014) reported that the probability of recording a porpoise buzz decreased by 15% in the ensonified area, and that the probability was positively related to the distance from the seismic ship; the decreased buzzing occurrence may indicate reduced foraging efficiency. Nonetheless, animals returned to the area within a few hours (Thompson et al. 2013). 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 (Kock 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 µPa$_{0\text{-peak}}$. 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 porpoises 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 µPa^2 · s. One porpoise moved away from the sound source but returned to natural movement patters within 8 h, and two porpoises had shorter and shallower dives but returned to natural behaviors within 24 h.

Odontocete reactions to large arrays of airguns are variable and, at least for delphinids, seem to be confined to a smaller radius than has been observed for the more responsive of the mysticetes and some other odontocetes. A ≥170 dB disturbance criterion (rather than ≥160 dB) is considered appropriate for delphinids, which tend to be less responsive than the more responsive cetaceans. 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).

7.1.4 Hearing Impairment and Other Physical Effects

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

Additional data are needed to determine the received sound levels at which small odontocetes would start to incur TTS upon exposure to repeated, low-frequency pulses of airgun sound with variable received levels. To determine how close an airgun array would need to approach in order to elicit TTS, one would (as a minimum) need to allow for the sequence of distances at which airgun pulses would occur, and for the dependence of received SEL on distance in the region of the seismic operation (e.g., Breitzke and Bohlen 2010; Laws 2012). At the present state of knowledge, it is also necessary to assume that the effect is directly related to total received energy (SEL); however, this assumption is likely an over-simplification (Finneran 2012). There is recent evidence that auditory effects in a given animal are not a simple function of received acoustic energy (Finneran 2015). Frequency, duration of the exposure, and occurrence of gaps within the exposure can also influence the auditory effect (Finneran and Schlundt 2010, 2011, 2013; Finneran et al. 2010a,b; Popov et al. 2011, 2013; Ketten 2012; Finneran 2012, 2015; Kastelein et al. 2012a,b; 2013b,c, 2014, 2015a, 2016a,b, 2017, 2018, 2019a,b, 2020a,b,c,d,e,f, 2021a,b, 2022; Supin et al. 2016).

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

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

Popov et al. (2016) reported that TTS produced by exposure to a fatiguing noise was larger during the first session (or naïve subject state) with a beluga whale than TTS that resulted from the same sound in subsequent sessions (experienced subject state). Similarly, several other studies have shown that some marine mammals (e.g., bottlenose dolphins, false killer whales) can decrease their hearing sensitivity in order to mitigate the impacts of exposure to loud sounds (e.g., Nachtigall and Supin 2013, 2014, 2015, 2016; Nachtigall et al. 2018; Finneran 2020; Kastelein et al. 2020g).

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

Several studies on TTS in porpoises (e.g., Lucke et al. 2009; Popov et al. 2011; Kastelein et al. 2012a, 2013a,b, 2014, 2015a) indicate that received levels that elicit onset of TTS are lower in porpoises than in other odontocetes. Based on studies that exposed harbor porpoises to one-sixth-octave noise bands ranging from 1 to 88.4 kHz, Kastelein et al. (2019c,d, 2020d,e,f) noted that susceptibility to TTS increases with an increase in sound less than 6.5 kHz but declines with an increase in frequency above 6.5 kHz. At a noise band centered at 0.5 kHz (near the lower range of hearing), the SEL required to elicit a 6 dB TTS is higher than that required at frequencies of 1 to 88.4 kHz (Kastelein et al. 2021a). Popov et al. (2011) examined the effects of fatiguing noise on the hearing threshold of Yangtze finless porpoises when exposed to frequencies of 32–128 kHz at 140–160 dB re 1 μPa for 1–30 min. They found that an exposure of higher level and shorter duration produced a higher TTS than an exposure of equal SEL but of lower level and longer duration. Popov et al. (2011) reported a TTS of 25 dB for a Yangtze finless porpoise that was exposed to high levels of 3-min pulses of half-octave band noise centered at 45 kHz with an SEL of 163 dB. For the harbor porpoise, Tougaard et al. (2015) 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). 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).

Initial evidence from exposures to non-pulses has also suggested that some pinnipeds (harbor seals in particular) incur TTS at somewhat lower received levels than do most small odontocetes exposed for similar durations (Kastak et al. 1999, 2005, 2008; Ketten et al. 2001; Kastelein et al. 2013a). Kastelein et al. (2012b) exposed two harbor seals to octave-band white noise centered at 4 kHz at three mean received SPLs of 124, 136, and 148 dB re 1 µPa; TTS >2.5 dB was induced at an SEL of 170 dB (136 dB SPL for 60 min), and the maximum TTS of 10 dB occurred after a 120-min exposure to 148 dB re 1 µPa or an SEL of 187 dB. Kastelein et al. (2013c) reported that a harbor seal unintentionally exposed to the same sound source with a mean received SPL of 163 dB re 1 µPa for 1 h induced a 44 dB TTS. A maximum TTS >45 dB was elicited from a harbor seal exposed to 32 kHz at 191 dB SEL (Kastelein et al. 2020c). For a harbor seal exposed to octave-band white noise centered at 4 kHz for 60 min with mean SPLs of 124–148 re 1 µPa, the onset of PTS would require a level of at least 22 dB above the TTS onset (Kastelein et al. 2013c). Harbor seals appear to be equally susceptible to incurring TTS when exposed to sounds from 2.5 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). Harbor seals may be able to decrease their exposure to underwater sound by swimming just below the surface where sound levels are typically lower than at depth (Kastelein et al. 2018). Reichmuth et al. (2016) exposed captive spotted and ringed seals to single airgun pulses with SELs of 165–181 dB and SPLs (peak to peak) of 190–207 re 1 µPa; no low-frequency TTS was observed. Similarly, no TTS was measured when a bearded seal was exposed to a single airgun pulse with an unweighted SEL of 185 dB and an SPL of 207 dB; however, TTS was elicited at 400 Hz when exposed to four to ten consecutive pulses with a cumulative unweighted SEL of 191–195 dB, and a weighted SEL of 167–171 dB (Sills et al. 2020). Kastelein et al. (2021b) found that susceptibility of TTS of California sea lions exposed to one-sixth-octave noise bands centered at 2, 4, and 8 kHz is similar to that of harbor seals, but at 16 kHz, California sea lion haring is less susceptible to TTS than harbor seals (Kastelein et al. 2022).

Hermannsen et al. (2015) reported that there is little risk of hearing damage to harbor seals or harbor porpoises when using single airguns in shallow water. SPLs for impulsive sounds are generally lower just below the water surface, and seals swimming near the surface are likely to be exposed to lower sound levels than when swimming at depth (Kastelein et al. 2018). However, the underwater sound hearing sensitivity for seals is the same near the surface and at depth (Kastelein et al. 2018). It is unlikely that a marine mammal would remain close enough to a large airgun array for sufficiently long to incur TTS, let alone PTS. However, Gedamke et al. (2011), based on preliminary simulation modeling that attempted to allow for various uncertainties in assumptions and variability around population means, suggested that some baleen whales whose CPA to a seismic vessel is 1 km or more could experience TTS.

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

Noise exposure criteria for marine mammals that were released by NMFS (2016, 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). Tougaard et al. (2022) indicate that there is empirical evidence to support the thresholds for very-high frequency cetaceans and pinnipeds in water, but caution that above 10 kHz for porpoise and outside of 3–16 kHz for seals, there are differences between the TTS thresholds and empirical data.

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. Williams et al. (2022) reported an increase in energetic cost of diving by narwhals that were exposed to airgun noise, as they showed marked cardiovascular and respiratory reactions.

It is possible that some marine mammal species (i.e., beaked whales) are especially susceptible to injury and/or stranding when exposed to strong transient sounds (e.g., Southall et al. 2007). Ten cases of cetacean strandings in the general area where a seismic survey was ongoing have led to speculation concerning a possible link between seismic surveys and strandings (Castellote and Llorens 2016). An analysis of stranding data found that the number of long-finned pilot whale strandings along Ireland's coast increased with seismic surveys operating offshore (McGeady et al. 2106). However, there is no definitive evidence that any of these effects occur even for marine mammals in close proximity to large arrays of airguns. Morell et al. (2017) examined the inner ears of long-finned pilot whales after a mass stranding in Scotland and reported damage to the cochlea compatible with over-exposure from underwater noise; however, no seismic surveys were occurring in the vicinity in the days leading up to the stranding.

Since 1991, there have been 72 Marine Mammal Unusual Mortality Events (UME) in the U.S. (NOAA 2023a). 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.

7.2 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 the source vessel 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; Kyhn et al. 2019; Landrø and Langhammer 2020); low levels of high-frequency sound from vessels have been shown to elicit responses in harbor porpoise (Dyndo et al. 2015). Increased levels of ship noise have also been shown to affect foraging by porpoise (Teilmann et al. 2015; Wisniewska et al. 2018). Wisniewska et al. (2018) suggest that a decrease in foraging success could have long-term fitness consequences.

Ship noise, through masking, can reduce the effective communication distance of a marine mammal if the frequency of the sound source is close to that used by the animal, and if the sound is present for a significant fraction of time (e.g., Richardson et al. 1995; Clark et al. 2009; Jensen et al. 2009; Gervaise et al. 2012; Hatch et al. 2012; Rice et al. 2014; Dunlop 2015; Erbe et al. 2016; Jones et al. 2017; Putland et al. 2017; Cholewiak et al. 2018). In addition to the frequency and duration of the masking sound, the strength, temporal pattern, and location of the introduced sound also play a role in the extent of the masking (Branstetter et al. 2013, 2016; Finneran and Branstetter 2013; Sills et al. 2017; Branstetter and Sills 2022). Branstetter et al. (2013) reported that time-domain metrics are also important in describing and predicting masking. In order to compensate for increased ambient noise, some cetaceans are known to increase the source levels of their calls in the presence of elevated noise levels from shipping, shift their peak frequencies, or otherwise change their vocal behavior (e.g., Parks et al. 2011, 2012, 2016a,b; Castellote et al. 2012; Melcón et al. 2012; Azzara et al. 2013; Tyack and Janik 2013; Luís et al. 2014; Sairanen 2014; Papale et al. 2015; Bittencourt et al. 2016; Dahlheim and Castellote 2016; Gospić and Picciulin 2016; Gridley et al. 2016; Heiler et al. 2016; Martins et al. 2016; O'Brien et al. 2016; Tenessen and Parks 2016; Fornet et al. 2018). Similarly, harbor seals increased the minimum frequency and amplitude of their calls in response to vessel noise (Matthews 2017); however, harp seals did not increase their call frequencies in environments with increased low-frequency sounds (Terhune and Bosker 2016).

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

Baleen whales are thought to be more sensitive to sound at these low frequencies than are toothed whales (e.g., MacGillivray et al. 2014), possibly causing localized avoidance of the proposed survey areas during seismic operations. Reactions of gray and humpback whales to vessels have been studied, and there is limited information available about the reactions of right whales and rorquals (fin, blue, and minke whales). Reactions of humpback whales to boats are variable, ranging from approach to avoidance (Payne 1978; Salden 1993). Baker et al. (1982, 1983) and Baker and Herman (1989) found humpbacks often move away when vessels are within several kilometers. Humpbacks seem less likely to react overtly when actively feeding than when resting or engaged in other activities (Krieger and Wing 1984, 1986). Increased levels of ship noise have been shown to affect foraging by humpback whales (Blair et al. 2016) and killer whales (Williams et al. 2021). Fin whale sightings in the western Mediterranean were negatively correlated with the number of vessels in the area (Campana et al. 2015). Minke whales and gray seals have shown slight displacement in response to construction-related vessel traffic (Anderwald et al. 2013).

Many odontocetes show considerable tolerance of vessel traffic, although they sometimes react at long distances if confined by ice or shallow water, if previously harassed by vessels, or have had little or no recent exposure to ships (Richardson et al. 1995). Dolphins of many species tolerate and sometimes approach vessels (e.g., Anderwald et al. 2013). Some dolphin species approach moving vessels to ride the bow or stern waves (Williams et al. 1992). Physical presence of vessels, not just ship noise, has been shown to disturb the foraging activity of bottlenose dolphins (Pirotta et al. 2015) and blue whales (Lesage et al. 2017b). 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.

Survey 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). 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 risk of collision of seismic vessels or towed/deployed equipment with marine mammals exists but would be extremely unlikely, because of the relatively slow operating speed (typically ~7–9 km/h) of the vessel during seismic operations, and the generally straight-line movement of the seismic vessel.

7.3 Numbers of Marine Mammals that could be “Taken by Harassment”

All takes would be anticipated to be Level B “takes by harassment” as described in § I, involving temporary changes in behavior. No injurious takes (Level A) would be expected and none have been requested. However, the predicted distances to the Level A threshold distances for two GI airguns were previously determined by L-DEO for a seismic survey in the Ross Sea (LGL Ltd 2022).

In the sections below, we describe methods to estimate the number of potential exposures to Level B sound levels for the low-energy surveys, and we 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 GoM.

7.3.1 Basis for Estimating "Takes"

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). The estimated numbers are based on the densities (numbers per unit area) of marine mammals expected to occur in the area in the absence of seismic surveys. 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 numbers of marine mammals that could be exposed to airgun sounds with received levels ≥160 dB re 1 μPa_{rms} (Level B) on one or more occasions have been estimated using a method recommended by NMFS for calculating the marine area that would be within the Level B threshold around the operating seismic source, along with the expected density of animals in the area. This method was developed to account in some way for the number of exposures as well as the number of individuals exposed. It involves selecting a seismic trackline(s) that could be surveyed on one day (~222 km). The area expected to be ensonified on one day was determined by multiplying the number of line km possible in one day by two times the 160-dB radius plus adding endcaps to the start and beginning of the line. The daily ensonified area was then multiplied by the number of survey days (10 days). The approach assumes that no marine mammals would move away or toward the trackline in response to increasing sound levels before the levels reach the specific thresholds as the source vessel approaches. To the extent that marine mammals tend to move away from seismic sources before the sound level reaches the criterion level and tend not to approach an operating airgun array, these estimates likely overestimate the numbers actually exposed to the specified level of sound.

To determine the number of marine mammals of most species expected in the survey area we used recently developed habitat-based marine mammal density estimates for the GoM (Garrison et al. 2022). The habitat-based models provide predicted marine mammal densities within 40 km^2 hexagons (~3.9 km sides and ~7 km across) covering the entire GoM for each month. To calculate expected densities specific to the survey area we created a 7 km perimeter around the survey area and used that to select the density hexagons for each species in each month. The 7 km distance was chosen for the perimeter to ensure that at least one full density hexagon outside the survey area in all directions was selected, providing a more robust sample for the calculations. We then calculated the mean of the predicted densities from the selected cells for each species and month. The highest mean monthly density was chosen for each species from the months of September to December.

For rough-toothed and Fraser's dolphins that were not included in Garrison et al. (2022), we used habitat-based marine mammal density estimates from Roberts et al. (2016a). The Roberts et al. (2016a) models consisted of 10 km x 10 km grid cells containing average annual densities for U.S. waters in the GoM. The same 7 km perimeter described above was used to select grid cells from the Roberts et al. (2016a) dataset, and the mean of the selected grid cells for each species was calculated to estimate the annual average density of the species in the survey area.

Table 3 shows estimated densities for cetacean species that could occur in the proposed survey area. Densities for those species not included in Table 3 are either estimated or assumed to be zero. There is uncertainty about the representativeness of the data and the assumptions used to estimate exposures below. Thus, for some species, the densities derived from the abundance models described above may not precisely represent the densities that would be encountered during the proposed seismic surveys.

TABLE 3. Monthly densities (# of individuals/km^2) of marine mammals for the proposed survey area off Texas, Northwestern Gulf of Mexico, based on Garrison et al. (2022). Annual densities for rough-toothed and Fraser's dolphins are from Roberts et al. (2016a). Potential months when surveys could occur are highlighted in gray. Maximum densities for the relevant time of year of the survey (or annual density) used to calculate takes are in bold.

Species Mean Densities (#/km^2)	Shelf* Atlantic Spotted Dolphin	Shelf* Common Bottlenose Dolphin	Clymene Dolphin	Pantropical Spotted Dolphin	Spinner Dolphin	Striped Dolphin	Risso's Dolphin	Fraser's Dolphin	Rough-toothed Dolphin	Black-fish	Pilot Whales	Beaked Whales	Sperm Whale	Rice's Whale
Monthly														
Jan	0.00068	0.34649	0	0	0	0	0	-	-	0	0	0	0	0
Feb	0.00074	0.33106	0	0	0	0	0	-	-	0	0	0	0	0
Mar	0.00062	0.30827	0	0	0	0	0	-	-	0	0	0	0	0
Apr	0.00049	0.14815	0	0	0	0	0	-	-	0	0	0	0	0
May	0.00060	0.15856	0	0	0	0	0	-	-	0	0	0	0	0
Jun	0.00078	0.27244	0	0	0	0	0	-	-	0	0	0	0	0
Jul	0.00113	0.28724	0	0	0	0	0	-	-	0	0	0	0	0
Aug	0.00141	0.27804	0	0	0	0	0	-	-	0	0	0	0	0
Sep	0.00071	0.27660	0	0	0	0	0	-	-	0	0	0	0	0
Oct	**0.00082**	0.18019	0	0	0	0	0	-	-	0	0	0	0	0
Nov	0.00078	0.16519	0	0	0	0	0	-	-	0	0	0	0	0
Dec	0.00069	**0.34024**	0	0	0	0	0	-	-	0	0	0	0	0
Annnual	-	-	-	-	-	-	-	0	**0.00362**	-	-	-	-	-

*Densities for oceanic populations were zero in all months.

The estimated numbers of individuals potentially exposed are based on the 160-dB re 1 µPa$_{rms}$ criterion for all marine mammals. It is assumed that marine mammals exposed to airgun sounds that strong could change their behavior sufficiently to be considered "taken by harassment". Table 4 shows the estimates of the number of marine mammals (with non-zero densities) that potentially could be exposed to ≥160 dB re 1 µPa$_{rms}$ during the proposed seismic surveys if no animals moved away from the survey vessel (see Appendix B for more details), along with the *Requested Take Authorization*. It should be noted that the exposure estimates assume that the proposed surveys would be completed. Thus, the following estimates of the numbers of marine mammals potentially exposed to sounds ≥160 dB re 1 µPa$_{rms}$ are precautionary and probably overestimate the actual numbers of marine mammals that could be involved. Take authorization is not being requested for species expected to have densities of zero in the study area (see Table 3).

Consideration should be given to the hypothesis that delphinids are less responsive to airgun sounds than are mysticetes. The 160-dB$_{rms}$ criterion currently applied by NMFS, on which the Level B estimates are based, was developed primarily using data from gray and bowhead whales. The estimates of "takes by harassment" of delphinids are thus considered precautionary. Available data suggest that the current use of a 160-dB criterion could be improved upon, as behavioral response might not occur for some percentage of marine mammals exposed to received levels >160 dB, whereas other individuals or groups might respond in a manner considered as "taken" to sound levels <160 dB (NMFS 2013b). The context of an exposure of a marine mammal to sound can affect the animal's initial response to the sound (e.g., Ellison et al. 2012; NMFS 2013; Hastie et al. 2021; Hückstädt et al. 2020; Southall et al. 2021; Miller et al. 2022). Southall et al. (2021) provide a detailed framework for assessing marine mammal behavioral responses to anthropogenic noise and note that use of a single threshold can lead to large errors in prediction impacts due to variability in responses between and within species.

TABLE 4. Estimates of the possible numbers of individual mid-frequency (MF) cetaceans that could be exposed to Level B thresholds during the proposed seismic surveys off Texas, Northwestern Gulf of Mexico.

Species	**Estimated Density (#/km^2)**	**Level B Ensonified Area (km^2)**	**Level B Takes**	**% of Pop.^{1}**	**% of Pop.^{2}**	**Requested Take Authorization^3**
Rough-toothed dolphin	0.0036	7,866	28	0.59	0.59	28
Bottenose dolphin	0.3402	7,866	2,676	1.93	1.72	2,676
Atlantic spotted dolphin	0.0008	7,866	6	0.05	0.42	**26**

N.A. means not available. [1] Requested take authorization provided as percent of population, based on abundance estimates from NMFS (2023). [2] Requested take authorization provided as percent of population based on abundance estimates from Roberts et al. (2016a). [3] Requested takes are calculated Level B takes, except those in bold which are based on mean group size for the GoM from Maze-Foley and Mullin (2006).

7.3.2 Conclusions

The proposed seismic surveys would involve towing a small source, up to two 105-in^3 GI airguns, that introduces pulsed sounds into the ocean. Routine vessel operations, other than the proposed seismic surveys, are conventionally assumed not to affect marine mammals sufficiently to constitute "taking". Although airgun operations, even with implementation of monitoring and mitigation measures, could result in a small number of Level B behavioral effects in some cetaceans, Level A effects are highly unlikely.

Airgun operations with implementation of the proposed monitoring and mitigation measures could result in a small number of Level B behavioral effects in some odontocetes, but Level A effects are highly unlikely. 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 B harassment are low percentages of the regional population sizes (Table 4).

The proposed activities would have no effect on ESA-listed marine mammal species, as these species are unlikely to be encountered in the proposed survey area. 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.

VIII. ANTICIPATED IMPACT ON SUBSISTENCE

The anticipated impact of the activity on the availability of the species or stocks of marine mammals for subsistence uses.

There is no subsistence hunting near the proposed survey area, so the proposed activity would not have any impact on the availability of the species or stocks for subsistence users.

IX. ANTICIPATED IMPACT ON HABITAT

The anticipated impact of the activity upon the habitat of the marine mammal populations, and the likelihood of restoration of the affected habitat.

The proposed seismic surveys would not result in any permanent impact on habitats used by marine mammals or to the food sources they use. The main impact issue associated with the proposed activity would be temporarily elevated noise levels and the associated direct effects on marine mammals, as discussed in § VII, above. Although there could be changes in behavior and other non-lethal, short-term, temporary impacts, and injurious or mortal impacts on a small number of fish or invertebrates within a few meters of the acoustic source, there would be no significant impacts of the marine seismic surveys on fish or marine invertebrate populations on which marine mammals feed. Relevant recent studies on the effects of seismic sound on marine invertebrates (crustaceans and cephalopods) and marine fish are discussed below.

Although research on the effects of exposure to airgun sound and other noise on marine invertebrates and fishes is increasing, many data gaps remain (Hawkins et al. 2015, 2020; Carroll et al. 2017; Popper and Hawkins 2019; Wale et al. 2021; Popper et al. 2022), including how particle motion rather than sound pressure levels affect invertebrates and fishes that are exposed to sound (Hawkins and Popper 2017; Popper and Hawkins 2018, 2019). It is important to note that while all invertebrates and fishes are likely sensitive to particle motion, no invertebrates and not all fishes (e.g., sharks) are sensitive to the sound pressure component. Rogers et al. (2021) found that sounds from a seismic survey measured above ambient conditions up to 10 km away for particle acceleration and up to 31 km for sound pressure.

Substrate vibrations caused by sounds may also affect the epibenthos, but sensitivities are largely unknown (Roberts and Elliott 2017). Nonetheless, several studies have found that substrate-borne vibration and sound elicit behavioral responses in crabs (e.g., Roberts et al. 2016b) and mussels (Roberts et al. 2015). Solan et al. (2015) also reported behavioral effects on sediment-dwelling invertebrates during sound exposure. Wang et al. (2022) reported that the amphipod *Corophium volutator* exhibited lower bioturbation rates when exposed to low-frequency noise, and they found potential stress responses by the bivalve *Limecola balthica*. 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 mollusks, were deemed to be the invertebrates most at risk from seismic impacts.

9.1 Effects of Sound on Marine Invertebrates

Effects of anthropogenic sounds on marine invertebrates are varied, ranging from no overt reactions to behavioral/physiological responses including stress, injuries, mortalities (Wale et al. 2013a,b; Aguilar de Soto 2016; Edmonds et al. 2016; Carroll et al. 2017; Weilgart 2017b; Elliott et al. 2019; Day et al. 2021) and stress (Celi et al. 2013; Vazzana et al. 2020). Jézéquel et al. (2021) recently reported that shipping noise can mask sounds produced by European lobster (*Homarus gammarus*), and that they may change sound production in response to noise.

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 rock lobsters (*Jasus edwardsi*) at a location 10–12 m below the surface to airgun sounds. The airgun source was started ~1–1.5 km from the study subjects and passed over the animals; thus, the scallops and lobsters were exposed to airgun sounds as close as 5–8 m away and up to 1.5 km from the source. Three different airgun configurations were used in the field: 45 in^3, 150 in^3 (low pressure), and 150 in^3 (high pressure), each with maximum peak-to-peak source levels of 191–213 dB re 1 µPa; maximum cumulative SEL source levels were 189–199 dB re 1 $\mu Pa^2 \cdot s$. Exposure to seismic sound was found to significantly increase mortality in the scallops, especially over a chronic time scale (i.e., months post-exposure), although not beyond naturally occurring rates of mortality (Day et al. 2017). Non-lethal effects were also recorded, including changes in reflex behavior time, other behavioral patterns, haemolymph chemistry, and apparent damage to statocysts (Day et al. 2016b, 2017). However, the scallops were reared in suspended lantern nets rather than their natural environment, which can result in higher mortality rates compared to benthic populations (Yu et al. 2010).

The female lobsters were maintained until the eggs hatched; no significant differences were found in the quality or quantity of larvae for control versus exposed subjects, indicating that the embryonic development of spiny lobster was not adversely affected by airgun sounds (Day et al. 2016a,b). No mortalities were reported for either control or exposed lobsters (Day et al. 2016a,b). Day et al. (2019, 2021, 2022) exposed rock lobster to the equivalent of a full-scale commercial seismic survey passing within 500 m, adult and juvenile lobsters exhibited impaired righting and damage to the sensory hairs of the statocyst. Lobsters that were exposed at a more distance range showed recovery, whereas those exposed at closer range had persistent impairment (Day et al. 2019, 2021, 2022). Day et al. (2021, 2022) noted that there was indication for slowed growth and physiological stress in juvenile lobsters after exposure. Adult lobsters that were collected from areas with high anthropogenic noise were shown to have pre-existing damage to the statocysts which were not damaged further upon exposure to airgun sounds (Day et al. 2020). However, lobsters from noisy environments appeared to be better able to cope with the damage than noise naïve lobsters; they did not show any disruption to the righting reflex (Day et al. 2020).

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

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

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

In total, 201 and 115 snow crab were tagged in Carson and Lilly canyons, respectively. Before, During, and After exposure periods to a single 2D seismic surveying line (5–8 hours duration) were matched in time across Control and Test sites—each site monitored an area 4 km^2. There were no obvious effects of seismic exposure on the movement ecology of adult male snow crab; variation in snow crab movement was primarily attributable to individual variation and factors like handling, water temperature and time of day. The authors concluded that the effects of seismic exposure on the behavior of adult male snow crab, are at most subtle and are "not likely to be a prominent threat to the fishery." There was also no evidence of physical damage to internal organs based on histological examinations (Morris et al. 2021). The study concluded that seismic exposure did not have any important effects on snow crab movement direction, and any variance in the results were shown to be individual-specific. Snow crab have also been considered to be less vulnerable to physiological damages from noise due to their absence of gas filled organs such as swim bladders that are sensitive to seismic exposures (Cote et al. 2020).

Hall et al. (2021) collected tissue samples to investigate the potential impact of seismic surveying on the transcriptome responses of snow crab hepatopancreas. The hepatopancreas is an organ that aids in the absorption and storage of nutrients and produces important digestive enzymes and is therefore assumed to be an indicator suitable for determining the effect of sound exposure effects on crab physiology and health.

Snow crabs were subjected to 2-D seismic noise in 2016 for 2 h and sampled before, and 18 h and three weeks after exposure. In 2017, 2-D seismic exposure was repeated, and samples were collected prior to seismic testing, and 1 day, 2 days, and 6 weeks after exposure. Additionally, in 2017 snow crabs were subjected 3-D seismic noises for 2 months and were sampled 6 weeks after exposure. Hall et al. (2021) identified nine transcripts with significantly higher expression after 2-D seismic exposure, and 14 transcripts with significant differential expression between the test and control sites. These included transcripts with functional annotations related to oxidation-reduction, immunity, and metabolism. Significant changes for these transcripts were not observed during the 2017. Thus, although transcript expression changes were detected in snow crab in response to seismic survey sound, the response was variable across years. Hall et al. (2021) concluded that although candidate molecular biomarkers identified in one field season (2016), they were not reliable indicators in the next year (2017), and further study is warranted.

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 $_{\text{0-pk}}$ were 204 dB re 1 µPa^2·s and 226 dB re 1 µPa. No macroscopic effects on soft tissues or the skeleton were noted days or months after the survey.

9.2 Effects of Sound on Fish

Popper et al. (2019a) and Popper and Hawkins (2021) recently reviewed the hearing ability of fishes, and potential impacts of exposure to airgun sound on marine fishes have been reviewed by Popper (2009), Popper and Hastings (2009a,b), Fay and Popper (2012), Weilgart (2017b), Hawkins and Popper (2018), Popper et al. (2019b), and Slabbekoorn et al. (2019); they include pathological, physiological, and behavioral effects. Radford et al. (2014), Putland et al. (2017), and de Jong et al. (2020) noted that masking of key environmental sounds or social signals could also be a potential negative effect from sound. Mauro et al. (2020) concluded that noise exposure may have significant effects on fish behavior which may subsequently affect fitness and survival).

Popper et al. (2014) presented guidelines for seismic sound level thresholds related to potential effects on fish. The effect types discussed include mortality, mortal injury, recoverable injury, temporary threshold shift, masking, and behavioral effects. Seismic sound level thresholds were discussed in relation to fish without swim bladders, fish with swim bladders, and fish eggs and larvae. Hawkins and Popper (2017) and Hawkins et al. (2020) cautioned that particle motion as well as sound pressure should be considered when assessing the effects of underwater sound on fishes.

Bruce et al. (2018) studied the potential behavioral impacts of a seismic survey in the Gippsland Basin, Australia, on three shark species: tiger flathead (*Neoplatycephalus richardsoni*), gummy shark (*Mustelus antarcticus*), and swellshark (*Cephaloscylum laticeps*). Sharks were captured and tagged with acoustic tags before the survey and monitored for movement via acoustic telemetry within the seismic area. The energy source used in the study was a 2530 in^3 array consisting of 16 airguns with a maximum SEL of 146 dB re 1 µPa^2·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 µPa^2 · s). Meekan et al. (2021) also reported that a commercial seismic source had no short- or long-term effects on the tropical demersal fish community on the North west Shelf of Western Australia, as no changes on species composition, abundance, size structure, behavior, or movement were reported. The source level of the airgun array was estimated as 228 dB SEL and 247 dB re 1 µPa m peak-to-peak pressure.

Fewtrell and McCauley (2012) exposed pink snapper (*Pagrus auratus*) and trevally (*Pseudocaranx dentex*) to pulses from a single airgun; the received sound levels ranged from 120–184 dB re 1 dB re 1 µPa^2 · s SEL. Increases in alarm responses were seen in the fish at SELs >147–151 dB re 1 µPa^2 · 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 µPa^2 · s.

Davidsen et al. (2019) outfitted Atlantic cod (*Gadus moruha*) and saithe (*Pollachius virens*) 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 $\mathrm{SEL_{cum}}$ ranged from 172–175 dB re 1 µPa^2·s. Both the cod and saithe changed swimming depth and horizontal position more frequently during exposure to the sound. The saithe became more dispersed in response to elevated sound levels. Both species exhibited behavioral habituation to the repeated exposures to sound.

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

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

McQueen et al. (2022) exposed wild Atlantic cod outfitted with acoustic transmitters on their spawning grounds to SELs up to 145 dB re 1 during a 1-week period of intermittent seismic shooting using two 40 in^3 airguns. The survival of cod or departure rates from the spawning grounds did not differ significantly between seismic exposure and control periods, indicating that cod were not displaced from spawning grounds after exposure to airgun sounds comparable to a survey several kilometers away from the site.

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

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

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

Andrews et al. (2014) conducted functional genomic studies on the inner ear of Atlantic salmon (*Salmo salar*) that had been exposed to seismic airgun sound. The airguns had a maximum SPL of ~145 dB re 1 $\mu Pa^2/Hz$ 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.

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.

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

X. ANTICIPATED IMPACT OF LOSS OR MODIFICATION OF HABITAT ON MARINE MAMMALS

The anticipated impact of the loss or modification of the habitat on the marine mammal populations involved.

The proposed activities are not expected to have any habitat-related effects that could cause significant or long-term consequences for individual marine mammals or their populations, because operations would be limited in duration (at most 10 days). However, a small minority of the marine mammals that are present near the proposed activity may be temporarily displaced by as much as a few kilometers by the planned activities.

XI. MITIGATION MEASURES

The availability and feasibility (economic and technological) of equipment, methods, and manner of conducting such activity or other means of effecting the least practicable adverse impact upon the affected species or stocks, their habitat, and on their availability for subsistence uses, paying particular attention to rookeries, mating grounds, and areas of similar significance.

Several marine mammal species could occur in the proposed survey area. To minimize the likelihood that impacts would occur to the species and stocks, airgun operations would be conducted in accordance with the MMPA and the ESA, including obtaining permission for incidental harassment or incidental 'take' of marine mammals and other endangered species and following requirements issued in the IHA and associated Incidental Take Statement (ITS).

The following subsections provide more detailed information about the mitigation measures that are an integral part of the planned activity. The procedures described here are based on best practices recommended in Richardson et al (1995), Pierson et al. (1998), Weir and Dolman (2007), Nowacek et al. (2013), Wright (2014), Wright and Cosentino (2015), and Acosta et al. (2017).

11.1 Planning Phase

Mitigation of potential impacts from the proposed activities begins during the planning phase of the proposed activity. Several factors were considered during the planning phase of the proposed activity, including

1. *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. Two GI airguns were determined to be the lowest practical source to meet the scientific objectives and to image the upper ~1 km of the geologic subsurface; if possible, a single GI airgun would be used. Although the proposed area of interest has been previously surveyed, the existence of the previous surveys would provide a good test of the novel positioning technology because those surveys were acquired using standard positioning technology.

2. *Survey Location and Timing*—The PI and DOE NETL considered potential times to carry out the proposed surveys, key factors taken into consideration included environmental conditions (i.e., the seasonal presence of marine mammals, sea turtles, and seabirds), weather conditions, and equipment. Most marine mammal and sea turtle species are expected to occur in the proposed survey area throughout the year. Fall was determined to be the most practical timing for the proposed surveys based on the occurrence of sea turtles, weather conditions, other operational requirements, and availability of researchers.
3. *Mitigation Zones*—During the planning phase, mitigation zones for the proposed marine seismic surveys were not derived from the farfield signature but calculated based on modeling by L-DEO for the exclusion zones (EZ) for the Level B (160 dB re 1µPa$_{\text{rms}}$) threshold. The background information and methodology for this are provided in Appendix A. L-DEO model results are used to determine the 160-dB$_{\text{rms}}$ radius for the airgun source down to a maximum depth of 2000 m (see Appendix A), as animals are generally not anticipated to dive below 2000 m (Costa and Williams 1999).

11.2 Mitigation During Operations

Several marine mammal species could 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, include: (1) monitoring by PSOs for marine mammals, and ESA-listed sea turtles and seabirds (diving/foraging) near the vessel, and observing for potential impacts of acoustic sources on fish; (2) PSO data and documentation; and (3) mitigation during operations (speed or course alteration; shut-down and ramp-up procedures; and special mitigation measures for rare species, species concentrations, and sensitive habitats). It would be unlikely that concentrations of large whales would be encountered within the 160-dB isopleth, but if they were, they would be avoided. Mitigation measures that would be adopted during the proposed surveys include (1) shut downs and (2) ramp ups.

11.2.1 Shut Down Procedures

The operating airgun(s) would be shut down if a marine mammal was seen within or approaching the EZ. The airgun array would be shut down if ESA-listed sea turtles or seabirds (diving/foraging) were observed within a designated EZ.

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

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

The airgun array would be ramped up gradually after a shut down for marine mammals but would not be required for ESA-listed sea turtles or seabirds. Ramp up procedures are described below.

11.2.2 Ramp Up Procedures

A ramp up procedure would be followed when the airgun array begins operating after a specified period without airgun operations. It is proposed that this period would be 30 min, as long as PSOs have maintained constant visual observations and no detections within the EZ have occurred. Ramp up would not occur if a marine mammal has not cleared the EZ as described earlier. As previously noted, for shut downs implemented for sea turtles and ESA-listed seabirds, no ramp up would be required, as long as the animal is no longer observed within the EZ.

Ramp up would begin by activating a single GI airgun and adding the second GI airgun 5 minutes later. Airguns would be added in a sequence such that the source level of the array would increase in steps not exceeding 6 dB per 5-min period. During ramp up, the PSOs would monitor the EZ, and if marine mammals or ESA-listed sea turtles/seabirds (diving/foraging) are sighted, a shut down would be implemented, respectively, as though the full array were operational.

Three 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. A monitoring report would be provided to NMFS, both the Permits and Conservation Division and the ESA Interagency Cooperation Division. With the proposed monitoring and mitigation provisions, potential effects on most, if not all, individuals would be expected to be limited to minor behavioral disturbance. Those potential effects would be expected to have negligible impacts both on individual marine mammals and on the associated species and stocks. Ultimately, survey operations would be conducted in accordance with all applicable U.S. federal regulations, including IHA and ITS requirements.

XII. PLAN OF COOPERATION

Where the proposed activity would take place in or near a traditional Arctic subsistence hunting area and/or may affect the availability of a species or stock of marine mammal for Arctic subsistence uses, the applicant must submit either a plan of cooperation or information that identifies what measures have been taken and/or will be taken to minimize any adverse effects on the availability of marine mammals for subsistence uses. A plan must include the following:

(i) A statement that the applicant has notified and provided the affected subsistence community with a draft plan of cooperation;

(ii) A schedule for meeting with the affected subsistence communities to discuss proposed activities and to resolve potential conflicts regarding any aspects of either the operation or the plan of cooperation;

(iii) A description of what measures the applicant has taken and/or will take to ensure that proposed activities will not interfere with subsistence whaling or sealing; and

(iv) What plans the applicant has to continue to meet with the affected communities, both prior to and while conducting activity, to resolve conflicts and to notify the communities of any changes in the operation.

Not applicable. The proposed activities would take place in the GoM, and no activities would take place in traditional Arctic subsistence hunting area.

XIII. MONITORING AND REPORTING PLAN

The suggested means of accomplishing the necessary monitoring and reporting that will result in increased knowledge of the species, the level of taking or impacts on populations of marine mammals that are expected to be present while conducting activities and suggested means of minimizing burdens by coordinating such reporting requirements with other schemes already applicable to persons conducting such activity. Monitoring plans should include a description of the survey techniques that would be used to determine the movement and activity of marine mammals near the activity site(s) including migration and other habitat uses, such as feeding.

UT proposes to sponsor marine mammal monitoring during the present project, in order to implement the proposed mitigation measures that require real-time monitoring and to satisfy the expected monitoring requirements of the IHA. UT's proposed Monitoring Plan is described below. UT understands that this Monitoring Plan would be subject to review by NMFS and that refinements may be required. The monitoring work described here has been planned as a self-contained project independent of any other related monitoring projects that may be occurring simultaneously in the same regions. UT is prepared to discuss coordination of its monitoring program with any related work that might be done by other groups insofar as this is practical and desirable.

13.1 Vessel-based Visual Monitoring

Observations by PSOs would take place during daytime airgun operations; the PSO(s) would scan the area around the vessel systematically with reticle binoculars (e.g., 7×50 Fujinon) and naked eye. Airgun operations would be shut down when marine mammals are observed within, or about to enter, designated EZs [see § XI above] where there is concern about potential effects on hearing or other physical effects. PSOs would also watch for marine mammals near the seismic vessel for at least 30 min prior to the planned start of airgun operations. Observations would also be made during daytime periods without seismic operations, such as during transits.

During seismic operations, three PSOs would be based aboard the source vessel. All PSOs would be appointed by UT with NMFS concurrence. During the majority of seismic operations, two PSOs would monitor for marine mammals around the seismic vessel. Use of two simultaneous observers would increase the effectiveness of detecting animals around the source vessel. PSO(s) would be on duty in shifts of duration no longer than 4 h, or per the IHA. Other crew would also be instructed to assist in detecting marine mammals and implementing mitigation requirements (if practical). Before the start of the seismic surveys, the crew would be given additional instruction regarding how to do so.

13.2 PSO Data and Documentation

PSOs would record data to estimate the numbers of marine mammals exposed to various received sound levels and to document apparent disturbance reactions or lack thereof. They would also record any observations of fish potentially affected by the sound sources. Data would be used to estimate numbers of animals potentially 'taken' by harassment (as defined in the MMPA). They would also provide information needed to order a shut down of the airguns when a marine mammal is within or near the EZ.

When a sighting is made, the following information about the sighting would be recorded:

1. Species, group size, age/size/sex categories (if determinable), behavior when first sighted and after initial sighting, heading (if consistent), bearing and distance from seismic vessel, sighting cue, apparent reaction to the airguns or vessel (e.g., none, avoidance, approach, paralleling, etc.), and behavioral pace.
2. Time, location, heading, speed, activity of the vessel, sea state, visibility, and sun glare.

The data listed under (2) would also be recorded at the start and end of each observation watch, and during a watch whenever there is a change in one or more of the variables.

All observations and shut downs would be recorded in a standardized format. Data would be entered into an electronic database. The accuracy of the data entry would be verified by computerized data validity checks as the data are entered and by subsequent manual checking of the database. These procedures would allow initial summaries of data to be prepared during and shortly after the field program, and would facilitate transfer of the data to statistical, graphical, and other programs for further processing and archiving.

Results from the vessel-based observations would provide

1. the basis for real-time mitigation (airgun shut down);
2. information needed to estimate the number of marine mammals potentially taken by harassment, which must be reported to NMFS;
3. data on the occurrence, distribution, and activities of marine mammals in the area where the seismic study is conducted;
4. information to compare the distance and distribution of marine mammals relative to the source vessel at times with and without seismic activity;
5. data on the behavior and movement patterns of marine mammals seen at times with and without seismic activity; and
6. any observations of fish potentially affected by the sound sources.

A report would be submitted to NMFS and DOE within 90 days after the end of the cruise. The report would describe the operations that were conducted and sightings of marine mammals near the operations. The report would provide full documentation of methods, results, and interpretation pertaining to all monitoring and would summarize the dates and locations of seismic operations and all marine mammal observations. The report would also include estimates of the number and nature of exposures that could result in "takes" of marine mammals by harassment or in other ways.

XIV. COORDINATING RESEARCH TO REDUCE AND EVALUATE INCIDENTAL TAKE

Suggested means of learning of, encouraging, and coordinating research opportunities, plans, and activities relating to reducing such incidental taking and evaluating its effects.

UT and DOE would coordinate with applicable U.S. agencies (e.g., NMFS), and would comply with all requirements.

XV. LITERATURE CITED

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

Acosta, A., N. Nino-Rodriquez, M.C. Yepes, and O. Boisseau. 2017. Mitigation provisions to be implemented for marine seismic surveying in Latin America: a review based on fish and cetaceans. **Aquat. Biol.** 26:199-216.

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.

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

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

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

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

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.

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.

Baumgartner, M.F., K.D. Mullin, L.N. May, and T.D. Leming. 2001. Cetacean habitats in the northern Gulf of Mexico. **Fish. Bull.** 99(2):219-219.

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., 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.

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.

Branstetter, B.K. and J.M. Sills. 2022. Mechanisms of auditory masking in marine mammals. **Animal Cogn.** https://doi.org/10.1007/s10071-022-01671-z

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

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

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

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

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

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

Burger, J. 2017. Avian resources of the northern Gulf of Mexico. p. 1353-1488 *In:* C. Ward (ed.). Habitats and biota of the Gulf of Mexico: before the Deepwater Horizon oil spill. Springer, New York, NY.

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.

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.

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

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

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

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.** 216:709-718.

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.

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.

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, U.K. 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.

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

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

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

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

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

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

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

Dahlheim, M.E. and J.E. Heyning. 1999. Killer whale *Orcinus orca* (Linnaeus, 1758). p. 281-322 *In*: S.H. Ridgway and R. Harrison (eds.), Handbook of Marine Mammals. Vol. 6. The Second Book of Dolphins and the Porpoises. Academic Press, San Diego, CA. 486 p.

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

Davis, R.W. and G.S. Fargion (eds). 1996. Distribution and abundance of cetaceans in the north-central and western Gulf of Mexico: Final Report. Volume II: Technical Report. OCS Study MMS 96-0027. Prepared by the Texas Institute of Oceanography and the National Marine Fisheries Service. U.S. Dept. of the Interior, Minerals Mgmt. Service, Gulf of Mexico OCS Region, New Orleans, LA. 357 p.

Davis, R.W., G.J. Worthy, B. Würsig et al. and S.K. Lynn. 1996. Diving behavior and at-sea movements of an Atlantic spotted dolphin in the Gulf of Mexico. **Mar. Mamm. Sci.** 12(4):569-581.

Davis, R.W., G.S. Fargion, N. May, T.D. Leming, M. Baumgartner, W.E. Evans, L.J. Hansen, and K. Mullin. 1998. Physical habitat of cetaceans along the continental slope in the north-central and western Gulf of Mexico. **Mar. Mamm. Sci.** 14(3):490-507.

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

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

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

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

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

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

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

Day, R.D., Q.P. Fitzgibbon, R.D. McCauley, K.B. Baker, and J.M. Semmens. 2022. The impact of seismic survey exposure on the righting reflex and moult cycle of southern rock lobster (*Jasus edwardsii*) puerulus larvae and juveniles. **Environ. Poll.** 309:119699.

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

DFO (Fisheries and Oceans Canada). 2004. Potential impacts of seismic energy on snow crab. DFO Can. Sci. Advis. Sec. Habitat Status Rep. 2004/003.

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

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, doi:10.1029/2010GC003126. 20 p.

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

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

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

Duffield, D.A., S.H. Ridgway, and L.H. Cornell. 1983. Hematology distinguishes coastal and offshore forms of dolphins (*Tursiops*). **Can. J. Zool**. 61(4):930-933.

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

Dunlop, R. 2018. The communication space of humpback whale social sounds in vessel noise. **Proc. Meet. Acoust.** 35(1):010001.

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. **Proc. Meet. Acoust.** 4ENAL 27(1):010026.

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.

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

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

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

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.

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.

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 Pap. SC/56/E28, **Int. Whal. Comm**., Cambridge, U.K.

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.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Finneran, J.J., 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.

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.

Foley, H.J., K. Pacifici, R.W. Baird, D.L. Webster, Z.T. Swaim, and A.J. Read. 2021. Residency and movement patterns of Cuvier's beaked whales *Ziphius cavirostris* off Cape Hatteras, North Carolina, USA. **Mar. Ecol. Prog. Ser**. 660:203-216.

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.

Fulling, G.L., K.D. Mullin, and C.W. Hubard. 2003. Abundance and distribution of cetaceans in outer continental shelf waters of the US Gulf of Mexico. **Fish. Bull.** 101:923-932.

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

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. 2021. Movement and seasonal energetics mediate vulnerability to disturbance in marine mammal populations. **Am. Nat.** 197(3):296-311.

Garrison, L., J. Litz, L. Dias Aichinger, G. Rappucci, A. Martinez, M. Soldevilla, et al. 2022. Cetacean and sea turtle spatial density model outputs from visual observations using line transect survey methods aboard NOAA vessel and aircraft platforms in the Gulf of Mexico from 2003-06-12 to 2019-07-31. NOAA National Centers for Environmental Information. Dataset. https://doi.org/10.25921/efv4-9z56.

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., Tampa, FL, 27 Nov.–2 Dec. 2011. 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.

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.

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.

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.

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. **Proc. Meet. Acoust.** 4ENAL 27(1):010030.

Griffin, R.B. and N.J. Griffin. 2003. Distribution, habitat partitioning, and abundance of Atlantic spotted dolphins, bottlenose dolphins, and loggerhead sea turtles on the eastern Gulf of Mexico continental shelf. Gulf of Mexico Sci. 21(1):3.

Griffin, R. and N.J. Griffin. 2004. Temporal variation in Atlantic spotted dolphin (*Stenella frontalis*) and bottlenose dolphin (*Tursiops truncatus*) densities on the west Florida continental shelf. Aquatic Mamm. 30(3):380-390.

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.

Gulf of Mexico Fishery Management Council. 2022. HAPC Overview 1. Accessed November 2022 at https://gulfcouncil.org/fishing-regulations/federal/hapc_overview-2/

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

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

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

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

Harris, C.M., L. Thomas, E.A. Falcone, J. Hildebrand, D. Houser, P.H. Kvadsheim, F.-P.A. Lam, P.J.O. Miller, D.J. Moretti, A.J. Read, H. Slabbekoorn, B.L. Southall, P.L. Tyack, D. Wartzok, and V.M. Janik. 2017. Marine mammals and sonar: dose–response studies, the risk-disturbance hypothesis and the role of exposure context. **J. Appl. Ecol**. 55(1):396-404.

Hart, K.M., M.M. Lamont, A.R. Sartain, and I. Fujisaki. 2014. Migration, foraging, and residency patterns for Northern Gulf loggerheads: implications of local threats and international movements. **PLoS One** 9(7):e103453. doi: 10.1371/journal.pone.0103453.

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

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

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

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

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. **Conserv. Biol.** 26(6):983-994.

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

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

Hawkins, A.D., A.E. Pembroke, and A.N. Popper. 2015. Information gaps in understanding the effects of noise on fishes and invertebrates. **Rev. Fish Biol. Fish.** 25(1):39-64.

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

Hayes, S.A., E. Josephson, K. Maze-Foley, and P.E. Rosel. 2021. U.S. Atlantic and Gulf of Mexico Marine mammal stock assessments 2020. NOAA Tech. Memo NMFS-NE-271. 394 p.

Hayes, S.A, E. Josephson, K. Maze-Foley, P.E. Rosel, and J. Wallace (eds). 2022. U.S. Atlantic and Gulf of Mexico Marine Mammal Stock Assessments 2021. 380 p.

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. Preliminary report from the Greenland Institute of Natural Resources. 59 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.

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

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

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

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

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

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

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

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

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

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

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. Oceanic Eng.** 37(4):576-588.

Hubard, C.W., K. Maze-Foley, K.D. Mullin, and W.W. Schroeder. 2004. Seasonal abundance and site fidelity of bottlenose dolphins (*Tursiops truncatus*) in the Mississippi Sound. Aquatic Mamm. 30:299-310.

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

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

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

Jefferson, T.A. and A.J. Schiro. 1997. Distribution of cetaceans in the offshore Gulf of Mexico. **Mamm. Rev.** 27:27-50.

Jefferson, T.A., C.R. Weir, R.C. Anderson, L.T. Balance, R.D. Kenney, and J.J. Kiszka. 2014. Global distribution of Risso's dolphin *Grampus griseus*: a review and critical evaluation. **Mamm. Rev.** 44:56-68.

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

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

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

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

Jones, E.L., G.D. Hastie, S. Smout, J. Onoufriou, N.D. Merchant, K.L. Brookes, and D. Thompson. 2017. Seals and shipping: quantifying population risk and individual exposure to vessel noise. **J. Appl. Ecol.** 54(6):1930-1940.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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. 695 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.

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

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

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

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

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

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

Kruse, S., D.K. Caldwell, and M.C. Caldwell. 1999. Risso's dolphin *Grampus griseus* (G. Cuvier, 1812). p. 183-212 *In:* S.H. Ridgway and R. Harrison (eds.), Handbook of marine mammals, Vol. 6: The second book of dolphins and the porpoises. Academic Press, San Diego, CA. 486 p.

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

Kunc, H.P., K.E. McLaughlin, and R. Schmidt. 2016. Aquatic noise pollution: implications for individuals, populations, and ecosystems. **Proc. R. Soc.** B 283:20160839.

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

LaBrecque, E., C. Curtice, J. Harrison, S.M. Van Parijs, and P.N. Halpin. Biologically important areas for cetaceans within U.S. waters – Gulf of Mexico region. **Aquatic Mamm.** 41(1):30-38.

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

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

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

Leatherwood, S., D.K. Caldwell, and H.E. Winn. 1976. Whales, dolphins, and porpoises of the western North Atlantic. A guide to their identification. NOAA Tech. Rep. NMFS Circ. 396. U.S. Dep. Comm., Washington, DC. 176 p.

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

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 Limited. 2022. Final Initial Environmental Evaluation of a Low-Energy Marine Geophysical Survey by RVIB *Nathaniel B. Palmer* in the Ross Sea, Antarctica, Austral Summer 2022/2023. LGL Report FA0244-2 prepared for National Science Foundation, Arlington, VA. 104 p. + app.

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.

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

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.

Malme, C.I. and P.R. Miles. 1985. Behavioral responses of marine mammals (gray whales) to seismic discharges. p. 253-280 *In:* G.D. Greene, F.R. Engelhard, and R.J. Paterson (eds.), Proc. Workshop on Effects of Explosives Use in the Marine Environment, Jan. 1985, Halifax, NS. Tech. Rep. 5. Can. Oil & Gas Lands Admin., Environ. Prot. Br., Ottawa, Ont. 398 p.

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

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

Mannocci, L., J.J. Roberts, D.L. Miller, and P.N. Halpin. 2017. Extrapolating cetacean densities to quantitatively assess human impacts on populations in the high seas. **Conserv. Biol.** 31(3):601–614. Models for all species available at: http://seamap.env.duke.edu/models/AFTT-2015/.

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

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

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

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

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

Maze-Foley, K. and K.D. Mullin. 2006. Cetaceans of the oceanic northern Gulf of Mexico: Distributions, group sizes and interspecific associations. **J. Cetacean Res. Manage.** 8(2):203-213.

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

McCauley, R.D., J. Fewtrell, A.J. Duncan, C. Jenner, M.-N. Jenner, J.D. Penrose, R.I.T. Prince, A. Adhitya, J. Murdoch, and K. McCabe. 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. Association, 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. from 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*:

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. **Proc. Meet. Acoust.** 4ENAL 27(1):040006.

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

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

McQueen, K., J.J. Meager, D. Nyqvist, J.E. Skjæraasen, E.M. Olsen, Ø. Karlsen, P.H. Kvadsheim, N.O. Handegard, T.N. Forland, and L. Doksæter Sivle. 2022. Spawning Atlantic cod (*Gadus morhua L.*) exposed to noise from seismic airguns do not abandon their spawning site. ICES J. Mar. Sci. 79(10):2697-2708.

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

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

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

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

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

Miller, G.W., V.D. Moulton, R.A. Davis, M. Holst, P. Millman, A. MacGillivray, and D. Hannay. 2005. Monitoring seismic effects on marine mammals—southeastern Beaufort Sea, 2001–2002. p. 511-542 *In:* S.L. Armsworthy, P.J. Cranford, and K. Lee (eds.), Offshore Oil and Gas Environmental Effects Monitoring/Approaches and Technologies. Battelle Press, Columbus, OH.

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

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

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

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

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.

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.

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

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

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

Moulton, V.D. and M. Holst. 2010. Effects of seismic survey sound on cetaceans in the Northwest Atlantic. Environ. Stud. Res. Funds Rep. 182. St. John's, Nfld. 28 p. Available at http://www.esrfunds.org/pdf/182.pdf.

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.

Mullin, K.D. 2007. Abundance of cetaceans in the oceanic northern Gulf of Mexico from 2003 and 2004 ship surveys. Available at http://aquaticcommons.org/15062/

Mullin, K.D. and G.L. Fulling. 2004. Abundance of cetaceans in the oceanic northern Gulf of Mexico, 1996–2001. **Mar. Mamm. Sci.** 20(4):787-807.

Mullin, K.D. and W. Hoggard. 2000. Visual surveys of cetaceans and sea turtles from aircraft and ships. p. 111-171 In R.W. Davis, W.E. Evans and B. Würsig (eds.), Cetaceans, sea turtles and seabirds in the northern Gulf of Mexico: distribution, abundance and habitat associations, Vol. II: technical report. U.S. Dep. Interior, Geol. Surv., Biol. Resour. Div., USGS/BRD/CR-1999-0006, and Minerals Manage. Serv., OCS Study MMS 2000-003.

Mullin, K.D., T.A. Jefferson, L.J. Hansen and W. Hoggard. 1994. First sightings of melon-headed whales (*Peponocephala electra*) in the Gulf of Mexico. **Mar. Mamm. Sci.** 10(3):342-348

Mullin, K.D., W. Hoggard and L.J. Hansen. 2004. Abundance and seasonal occurrence of cetaceans in outer continental shelf and slope waters of the north-central and northwestern Gulf of Mexico. **Gulf Mex. Sci.** 22:62-73.

Nachtigall, P.E. and A.Y. Supin. 2013. Hearing sensation changes when a warning predicts a loud sound in the false killer whale. Abstr. 3rd Int. Conf. Effects of Noise on Aquatic Life, Budapest, Hungary, August 2013.

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 predicts 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.

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. **Function. Ecol.** 27:314-322.

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. 2013. Effects of oil and gas activities in the Arctic Ocean: supplemental draft environmental impact statement. U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Office of Protected Resources.

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. Depart. Commerce, National Oceanic and Atmospheric Administration. 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.

NMFS. 2023. Taking marine mammals incidental to geophysical surveys in the Gulf of Mexico. Proposed rule. **Fed. Reg.** 88(3, 5 January):916-948.

NOAA. 2023. Active and closed Unusual Mortality Events. Accessed on January 2023 at https://www.fisheries.noaa.gov/national/marine-life-distress/active-and-closed-unusual-mortality-events.

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.** 120:235-244.

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

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

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

OBIS (Ocean Biogeographic Information System). 2022. Data from the Ocean Biogeographic Information System. Intergovernmental Oceanographic Commission of UNESCO. Accessed July 2022 at http://www.iobis.org.

Odell, D.K. and K.M. McClune. 1999. False killer whale *Pseudorca crassidens* (Owen, 1846). p. 213-243 *In*: S.H. Ridgway and R. Harrison (eds.), Handbook of marine mammals, Vol. 6: The second book of dolphins and the porpoises. Academic Press, San Diego, CA. 486 p.

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

Ortega-Ortiz, J.G. 2002. Multiscale analysis of cetacean distribution in the Gulf of Mexico. PhD Dissertation, Texas A&M University.

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

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

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

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

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

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

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

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

Perrin, W.F., D.K. Caldwell, and M.C. Caldwell. 1994a. Atlantic spotted dolphin *Stenella frontalis* (G. Cuvier, 1829). p. 173-190 *In*: S.H. Ridgway and R.J. Harrison (eds.), Handbook of marine mammals, Vol. 5: The first book of dolphins. Academic Press, San Diego, CA. 416 p.

Perrin, W.F., S. Leatherwood, and A. Collet. 1994b. Fraser's dolphin *Lagenodelphis hosei* Fraser, 1956. p. 225-240 *In*: S.H. Ridgway and R. Harrison (eds.), Handbook of marine mammals, Vol. 5: The first book of dolphins. Academic Press, London, U.K. 416 p.

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, U.K., 23–25 June 1998.

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.

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.

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. Exper. 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.

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

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

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

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

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

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

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

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

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

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

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

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

Putland, R.L., N.D. Merchant, A. Farcas, and C.A. Radford. 2017. Vessel noise cuts down communication space for vocalizing fish and marine mammals. **Glob. Change Biol.** 24(4):1708-1721.

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

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

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

Reyes, J.C. 1991. The conservation of small cetaceans: a review. Report prepared for the Secretariat of the Convention on the Conservation of Migratory Species of Wild Animals. UNEP.

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

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

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 (Abstract).

Roberts, J.J., B.D. Best, L. Mannocci, E. Fujioka, P.N. Halpin, D.L. Palka, L.P. Garrison, K.D. Mullin, T.V. Cole, C.B. Khan, and W.A. McLellan. 2016a. Habitat-based cetacean density models for the US Atlantic and Gulf of Mexico. **Sci. Rep.** 6(1):22615.

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

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

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

Roberts, L. 2022. Habitat-based marine mammal density models for the U.S. Atlantic: Latest Versions. Downloaded December 2022 at https://seamap.env.duke.edu/models/Duke/EC/

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.

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

Rolland, R.M., S.E. Parks, K.E. Hunt, M. Castellote, P.J. Corkeron, D.P. Nowacek, S.K. Water, and S.D. Kraus. 2012. Evidence that ship noise increases stress in right whales. **Proc. R. Soc. B** 279:2363-2368.

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.

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

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. **Proc. Meet. Acoust.** 4ENAL 27(1):040010.

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.

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

Simmonds, M.P., S.J. Dolman, M. Jasny, E.C.M. Parsons, L. Weilgart, A.J. Wright, and R. Leaper. 2014. Marine noise pollution – Increasing recognition but need for more practical action. **J. Ocean Tech.** 9:71-90.

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

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

Solé, 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.

Solé, M., P. Sigray, M. Lenoir, M. van der Schaar, E. Lalander, and M. André. 2017. Offshore exposure experiments on cuttlefish indicate received sound pressure and particle motion levels associated with acoustic trauma. **Sci. Rep.** 7:45899.

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

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

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

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 U.K. waters. **J. Cetac. Res. Manage.** 8(3):255-263.

Stone, C.J., K. Hall, S. Mendes, and M.L. Tasker. 2017. The effects of seismic operations in UK waters: analysis of marine mammal observer data. **J. Cetacean Res. Manage.** 16:71-85.

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.

Sychenko, O., G. Gailey, R. Racca, A. Rutenko, L. Aerts, and R. Melton. 2017. Gray whale abundance and distribution relative to three seismic surveys near their feeding habitat in 2015. Abstract and presentation at the Society for Marine Mammalogy's 22nd Biennial Conference on the Biology of Marine Mammals, 22-27 October, Halifax, Nova Scotia, Canada.

Teilmann, J., D.M. Wisniewska, M. Johnson, L.A. Miller, U. Siebert, R. Dietz, S. Sveegaard, A. Galatius, and P.T. Madsen. 2015. Acoustic tags on wild harbour porpoises reveal context-specific reactions to ship noise. *In*: 18. Danske Havforskermøde 2015, 28-30 January 2015.

Tenessen, J.B. and S.E. Parks. 2016. Acoustic propagation modeling indicates vocal compensation in noise improves communication range for North Atlantic right whales. **Endang. Species Res.** 30:225-237.

Terhune, J.M. and T. Bosker. 2016. Harp seals do not increase their call frequencies when it gets noisier. p. 1149-1153 In: A.N. Popper and A. Hawkins (eds.), The effects of noise on aquatic life II. Springer, New York, NY. 1292 p.

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

Thode, A.M., K.H. Kim, S.B. Blackwell, C.R. Greene, Jr., C.S. Nations, T.L. McDonald, and A.M. Macrander. 2012. Automated detection and localization of bowhead whale sounds in the presence of seismic airgun surveys. **J. Acoust. Soc. Am.** 131(5):3726-3747.

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

Thompson, 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.

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.

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

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

Tyack, P.L. and V.M. Janik. 2013. Effects of noise on acoustic signal production in marine mammals. p. 251-271 In: H. Brumm (ed.), Animal communication and noise. Springer, Berlin, Heidelberg, Germany. 453 p.

van Beest, F.M., J. Teilmann, L. Hermannsen, A. Galatius, L. Mikkelsen, S. Sveegaard, J.D. Balle, R. Dietz, and J. Nabe-Nielsen. 2018. Fine-scale movement responses of free-ranging harbour porpoises to capture, tagging and short-term noise pulses from a single airgun. **R. Soc. Open Sci.** 5:170110.

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

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

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.

Vollmer, N.L. 2011. Population structure of common bottlenose dolphins in coastal and offshore waters of the Gulf of Mexico revealed by genetic and environmental analyses. Ph.D. Dissertation from University of Louisiana at Lafayette. 420 p.

Wale, M.A., S.D. Simpson, and A.N. Radford. 2013a. Size-dependent physiological responses of shore crabs to single and repeated playback of ship noise. **Biol. Lett.** 9:20121194.

Wale, M.A., S.D. Simpson, and A.N. Radford. 2013b. Noise negatively affects foraging and antipredator behaviour in shore crabs. **Anim. Behav.** 86:111-118.

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

Walker, J.L., C.W. Potter, and S.A. Macko. 1999. The diets of modern and historic bottlenose dolphin populations reflected through stable isotopes. **Mar. Mamm. Sci.** 15(2):335-350.

Wang, S.V., A. Wrede, N. Tremblay, and J. Beermann. 2022. Low-frequency noise pollution impairs burrowing activities of marine benthic invertebrates. **Environ. Poll.** 310:119899.

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. p. 111-124 *In:* A. Butterworth (ed.) Marine mammal welfare human induced change in the marine environment and its impacts on marine mammal welfare. Springer.

Weilgart, L.S. 2017b. The impact of ocean noise pollution on fish and invertebrates. Report for OceanCare, Switzerland. 23 p.

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., 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., Y.V. Ivashchenko, G.A. Tsidulko, A.M. Burdin, and R.L. Brownell, Jr. 2002. Influence of seismic surveys on western gray whales off Sakhalin Island, Russia in 2001. Paper SC/54/BRG14, IWC, Western Gray Whale Working Group Meet., 22-25 Oct., Ulsan, South Korea. 12 p.

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

Wensveen, P.J., A.M. von Benda-Beckmann, M.A. Ainslie, F.P.A. Lam, P.H. Kvadsheim, P.L. Tyack, and P.J.O. Miller. 2015. How effectively do horizontal and vertical response strategies of long-finned pilot whales reduce sound exposure from naval sonar? **Mar. Environ. Res.** 106:68-81.

Wiley, D.N., C.A. Mayo, E.M. Maloney, and M.J. Moore. 2016. Vessel strike mitigation lessons from direct observations involving two collisions between noncommercial vessels and North Atlantic right whales (*Eubaleana glacialis*). **Mar. Mammal Sci.** 32(4):1501-1509.

Williams, R., E. Ashe, L. Yruretagoyena, N. Mastick, M. Siple, J. Wood, R. Joy, R. Langrock, S. Mews, and E. Finne. 2021. Reducing vessel noise increases foraging in endangered killer whales. **Mar. Poll. Bull.** 173:112976.

Williams, T.M, W.A. Friedl, M.L. Fong, R.M. Yamada, P. Sideivy, and J.E. Haun. 1992. Travel at low energetic cost by swimming and wave-riding bottlenose dolphins. **Nature** 355(6363):821-823.

Williams, T.M., S.B. Blackwell, O. Tervo, E. Garde, M.H.S. Sinding, B. Richter, and M.P. Heide-Jørgensen. 2022. Physiological responses of narwhales to anthropogenic noise: a case study with seismic airguns and vessel traffic in the Arctic. **Funct. Ecol.** 36:2251-2266.

Willis, K.L., J. Christensen-Dalsgaard, D.R. Ketten, and C.E. Carr. 2013. Middle ear cavity morphology is consistent with an aquatic origin for testudines. **PLoS One** 8(1):e54086.

Winsor, M.H., L.M. Irvine, and B.R. Mate. 2017. Analysis of the spatial distribution of satellite-tagged sperm whales (*Physeter macrocephalus*) in close proximity to seismic surveys in the Gulf of Mexico. **Aquatic Mamm.** 43(4):439-446.

Wisniewska, D.M., M. Johnson, J. Teilmann, U. Siebert, A. Galatius, R. Dietz, and P.T. Madsen. 2018. High rates of vessel noise disrupt foraging in wild harbour porpoises (*Phocoena phocoena*). **Proc. R. Soc. B** 285:20172314.

Wittekind, D., J. Tougaard, P. Stilz, M. Dähne, K. Lucke, C.W. Clark, S. von Benda-Beckmann, M. Ainslie, and U. Siebert. 2016. Development of a model to assess masking potential for marine mammals by the use of airguns in Antarctic waters. p. 1243-1249 *In:* A.N. Popper and A. Hawkins (eds.) The effects of noise on aquatic life II. Springer, New York, NY. 1292 p.

Wole, O.G. and E.F. Myade. 2014. Effect of seismic operations on cetacean sightings off-shore Akwa Ibom State, south-south, Nigeria. **Int. J. Biol. Chem. Sci.** 8(4):1570-1580.

Wright, A.J. 2014. Reducing impacts of human ocean noise on cetaceans: knowledge gap analysis and recommendations. 98 p. World Wildlife Fund Global Arctic Programme, Ottawa, ON.

Wright, A.J. and A.M. Consentino. 2015. JNCC guidelines for minimizing the risk of injury and disturbance to marine mammals from seismic surveys: we can do better. **Mar. Poll. Bull.** 100(1):231-239.

Wright, A.J., T. Deak, and E.C.M. Parsons. 2011. Size matters: management of stress responses and chronic stress in beaked whales and other marine mammals may require larger exclusion zones. **Mar. Poll. Bull.** 63(1-4):5-9.

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

Würsig, B., S.K. Lynn, T.A. Jefferson, and K.D. Mullin. 1998. Behaviour of cetaceans in the northern Gulf of Mexico relative to survey ships and aircraft. **Aquatic Mamm.** 24(1):41-50.

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

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

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

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

Yu, Z.H., H.S. Yang, B.Z. Liu, Q. Xu, K. Xing, and L.B. Zhang. 2010. Growth, survival and immune activity of scallops, *Chlamys farreri* Jones et Preston, compared between suspended and bottom culture in Haizhou Bay, China. **Aquacult. Res.** 41:814-827.

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 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* NFS and USGS 2011). as a function of distance from the airguns, for the two 105-in^3 GI airguns. This modeling approach uses ray tracing for the direct wave traveling from the array to the receiver and its associated source ghost (reflection at the air-water interface in the vicinity of the array), in a constant-velocity half-space (infinite homogeneous ocean layer, unbounded by a seafloor).

Propagation measurements of pulses from the 36-airgun array at a tow depth of 6 m have been reported in deep water (~1600 m), intermediate water depth on the slope (~600–1100 m), and shallow water (~50 m) in the GoM in 2007–2008 (Tolstoy et al. 2009; Diebold et al. 2010). For deep and intermediate-water cases, the field measurements cannot be used readily to derive mitigation radii, as at those sites the calibration hydrophone was located at a roughly constant depth of 350–500 m, which may not intersect all the sound pressure level (SPL) isopleths at their widest point from the sea surface down to the maximum relevant water depth (~2000 m) for marine mammals (Costa and Williams 1999). Figures 2 and 3 in Appendix H of the NSF and USGS (2011) 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 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.

In deep and intermediate-water depths, comparisons at short ranges between sound levels for direct arrivals recorded by the calibration hydrophone and model results for the same array tow depth are in good agreement (Fig. 12 and 14 in Appendix H of the PEIS). Consequently, isopleths falling within this domain can be predicted reliably by the L-DEO model, although they may be imperfectly sampled by measurements recorded at a single depth. At greater distances, the calibration data show that seafloor-reflected and sub-seafloor-refracted arrivals dominate, whereas the direct arrivals become weak and/or incoherent (Fig. 11, 12, and 16 in Appendix H of the PEIS). Aside from local topography effects, the region around the critical distance (~5 km in Fig. 11 and 12, and ~4 km in Fig. 16 in Appendix H of the PEIS) is where the observed levels rise closest to the mitigation model curve. However, the observed sound levels are found to fall almost entirely below the mitigation model curve (Fig. 11, 12, and 16 in Appendix H of the PEIS). Thus, analysis of the GoM calibration measurements demonstrates that although simple, the L-DEO model is a robust tool for conservatively estimating mitigation radii. In shallow water (<100 m), the depth of the calibration hydrophone (18 m) used during the GoM calibration survey was appropriate to sample the maximum sound level in the water column, and the field measurements reported in Table 1 of Tolstoy et al. (2009) for the 36-airgun array at a tow depth of 6 m can be used to derive mitigation radii.

The proposed surveys would acquire data with two 105-in^3 GI guns (separated by up to 2.4 m) at a tow depth of ~3–4 m. Table A-1 shows the distances at which the 160-dB re 1µPa$_{rms}$ sound level is expected to be received for the 2-GI airgun configuration (totaling 210 in^3) at a 4-m tow depth. For deep water (>1000 m), we use the deep-water radii obtained from L-DEO model results down to a maximum water depth of 2000 m (Fig. A-1 and A-2). 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).

The shallow-water radii are obtained by scaling the empirically derived measurements from the GoM calibration survey to account for the differences in volume and tow depth between the calibration survey (6600 in^3 at 6 m tow depth) and the proposed survey (210 in^3 at 4 m tow depth). A simple scaling factor is calculated from the ratios of the isopleths calculated by the deep-water L-DEO model, which are essentially a measure of the energy radiated by the source array:

- 150 decibel (dB) Sound Exposure Level (SEL)[1] corresponds to deep-water maximum radii of 725.96 m for the two 105 in^3 GI-guns at 4 m tow depth (Fig. A-1), and 7,244 m for the 6600 in^3 at 6-m tow depth (Fig. A-2), yielding a scaling factor of 0.10 to be applied to the shallow-water 6-m tow depth results.
- 165 dB SEL corresponds to deep-water maximum radii of 128.2 m for the two 105 in^3 GI-guns at a 4 m tow depth, and 1,284 m for a 6-m tow depth, yielding a scaling factor of 0.10 to be applied to the shallow-water 6-m tow depth results.
- 170 dB SEL corresponds to deep-water maximum radii of 72.7 for the two 105 in^3 GI-guns at a 4 m tow depth (Fig. A-1), and 719 m for the 6600 in^3 at 6-m tow depth (Fig. A-2), yielding a scaling factor of 0.10.
- 185 dB SEL corresponds to deep-water maximum radii of 12.86 m for the two 105 in^3 at 4-m tow depth, and 126.3 m for a 6-m tow depth, yielding a scaling factor of 0.11 to be applied to the shallow-water 6-m tow depth results.

Measured 160-, 175-, 180-, 190- and 195-dB re 1μPa_{rms} distances in shallow water for the 36-airgun array towed at 6 m depth were 17.5 km, 2.84 km, 1.6 km, 458 m and 240 m, respectively, based on a 95th percentile fit (Tolstoy et al. 2009). Multiplying by the scaling factor to account for the tow depth and discharge volume differences between the 6600 in^3 airgun array at 6 m tow depth and the 210 in^3 GI airgun array at 4 m tow depth yields distances of 1.75 km, 284 m, 160 m, 46 m, and 26 m, respectively.

Table A-1 shows the distances at which the 160-, 175-, 180-, 190 and 195-dB re 1μPa_{rms} sound levels are expected to be received for the two 105 in^3 GI-guns at 4 m tow depth. The 160-dB level is the behavioral disturbance criterion (Level B) that is used by NMFS to estimate anticipated takes for marine mammals; a 175-dB level is used by the National Marine Fisheries Service (NMFS), based on U.S. DoN (2017), to determine behavioral disturbance for sea turtles.

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[1] SEL (measured in dB re 1 $\mu Pa^2 \cdot s$) is a measure of the received energy in the pulse and represents the SPL that would be measured if the pulse energy were spread evenly across a 1-s period. Because actual seismic pulses are less than 1 s in duration in most situations, this means that the SEL value for a given pulse is usually lower than the SPL calculated for the actual duration of the pulse. In this EA, we assume that rms pressure levels of received seismic pulses would be 10 dB higher than the SEL values predicted by L-DEO's model.

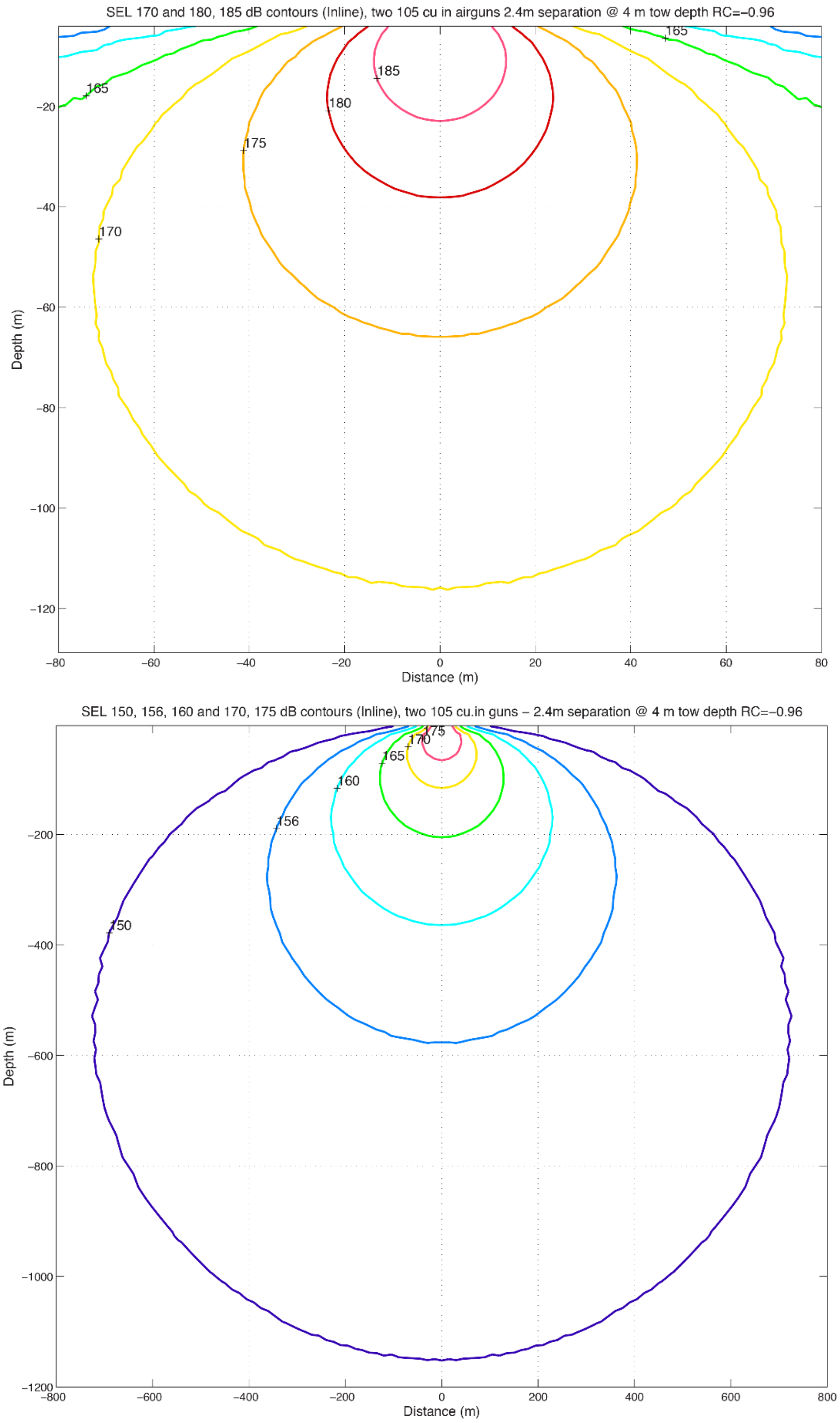

FIGURE A-1. Modeled deep-water received sound exposure levels (SELs) from the two 105-in^3 GI guns, with a 2.4-m gun separation, planned for use during the proposed surveys at a 4-m tow depth. Received rms levels (SPLs) are expected to be ~10 dB higher. The radius to the 150-dB SEL isopleth is a proxy for the 160-dB rms isopleth. The upper plot is a zoomed-in version of the lower plot.

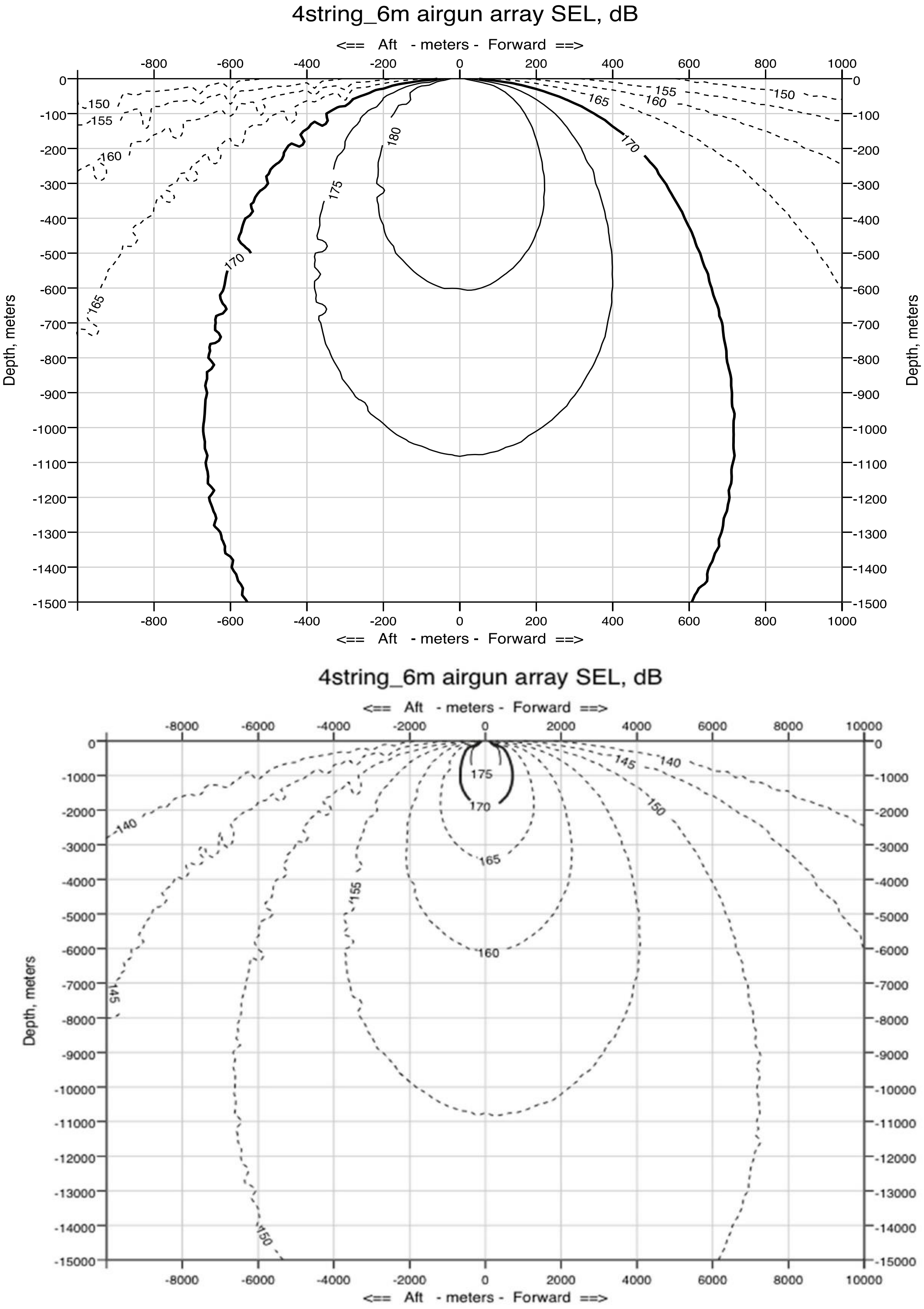

FIGURE A-2. Modeled deep-water received sound exposure levels (SELs) from the 36-airgun array at a 6-m tow depth used during the GoM calibration survey. Received rms levels (SPLs) are expected to be ~10 dB higher. The plot at the top provides the radius to the 170 dB SEL isopleth as a proxy for the 180-dB rms isopleth, and the plot at the bottom provides the radius to the 150-dB SEL isopleth as a proxy for the 160-dB rms isopleth.

TABLE A-1. Level B. Predicted distances to the 160 dB and 175 dB re 1 µPa$_{rms}$ sound levels that could be received from two 105-in^3 GI guns (separated by 2.4 m, at a tow depth of 4 m) that would be used during the seismic surveys in the Gulf of Mexico (model results provided by L-DEO).

Airgun Configuration	**Water Depth (m)**[1]	**Predicted rms Distances (m)**	
		160 dB	**175 dB**
Two 105-in^3 GI guns	>1000	726[1]	128[1]
	100-1000	1,089[2]	192[2]
	<100	1,750[3]	284[3]

[1] Distance is based on L-DEO model results.

[2] Distance is based on L-DEO model results with a 1.5 × correction factor between deep and intermediate water depths.

[3] Distance is based on empirically derived measurements in the GoM with scaling applied to account for differences in tow depth.

A recent retrospective analysis of acoustic propagation of R/V *Langseth* sources in a coastal/shelf environment from the Cascadia Margin off Washington suggests that predicted (modeled) radii (using an approach similar to that used here) for R/V *Langseth* sources were 2–3 times larger than measured in shallow water, so in fact, as expected, were very conservative (Crone et al. 2014). Similarly, data collected by Crone et al. (2017) during a survey off New Jersey in 2014 and 2015 confirmed that in situ measurements and estimates of the 160- and 180-dB distances collected by R/V *Langseth* hydrophone streamer were 2–3 times smaller than the predicted operational mitigation radii. In fact, five separate comparisons conducted of the L-DEO model with in situ received level[3] have confirmed that the L-DEO model generated conservative mitigation zones, resulting in significantly larger zones 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, but did not establish new thresholds for Level B Harassment. The new noise exposure criteria for marine mammals account for the newly-available scientific data on temporary threshold shifts (TTS), the expected offset between TTS and PTS thresholds, differences in the acoustic frequencies to which different marine mammal groups are sensitive, and other relevant factors, as summarized by Finneran (2016).

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

Literature Cited

Barton, P., J. Diebold, and S. Gulick. 2006. Balancing mitigation against impact: a case study from the 2005 Chicxulub seismic survey. **Eos Trans. Amer. Geophys. Union** 87(36), Joint Assembly Suppl., Abstr. OS41A-04. 23–26 May, Balitmore, MD.

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

Crone, T.J., M. Tolstoy, and H. Carton. 2014. Estimating shallow water sound power levels and mitigation radii for the R/V *Marcus G. Langseth* using an 8 km long MCS streamer. **Geochem., Geophys., Geosyst.** 15(10):3793-3807.

Crone, T.J., M. Tolstoy, and H. Carton. 2017. Utilizing the R/V *Marcus G. Langseth*'s streamer to measure the acoustic radiation of its seismic source in the shallow waters of New Jersey's continental shelf. **PloS ONE** 12(8):e0183096. http://doi.org/10.1371/journal.pone.0183096.

Diebold, J.B., M. Tolstoy, P.J. Barton, and S.P. Gulick. 2006. Propagation of exploration seismic sources in shallow water. **Eos Trans. Amer. Geophys. Union** 87(36), Joint Assembly Suppl., Abstr. OS41A-03. 23–26 May, Baltimore, MD.

Diebold, J.B., M. Tolstoy, L. Doermann, S.L. Nooner, S.C. Webb, and T.J. Crone. 2010. R/V *Marcus G. Langseth* seismic source: modeling and calibration. **Geochem. Geophys. Geosyst.** 11(12):Q12012. http://doi.org/10.1029/2010GC003126. 20 p.

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

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

NMFS. 2016. Technical guidance for assessing the effects of anthropogenic sound on marine mammal hearing: underwater acoustic thresholds for onset of permanent and temporary threshold shifts. U.S. Dept. of Commer., NOAA. 178 p.

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

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.