Request by ION GeoVentures for an Incidental Harassment Authorization to Allow the Incidental Take of Marine Mammals during a 2-D Seismic Survey off the U.S. East Coast in Summer–Fall 2016

submitted by

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TABLE OF CONTENTS

SUMMARY **1**

I. OPERATIONS TO BE CONDUCTED **2**

Overview of the Activity **2**

Vessel Specifications **2**

Airgun Array Description **4**

Airgun Array Source Signature 5

Sound Propagation Model 6

II. DATES, DURATION, AND REGION OF ACTIVITY **10**

III. SPECIES AND NUMBERS OF MARINE MAMMALS IN AREA **10**

IV. STATUS, DISTRIBUTION AND SEASONAL DISTRIBUTION OF AFFECTED SPECIES OR STOCKS OF MARINE MAMMALS **11**

Mysticetes **13**

North Atlantic Right Whale (Eubalaena glacialis) 13

Humpback Whale (Megaptera novaeangliae) 17

Common Minke Whale (Balaenoptera acutorostrata) 18

Bryde's Whale (Balaenoptera edeni) 18

Sei Whale (Balaenoptera borealis) 19

Fin Whale (Balaenoptera physalus) 19

Blue Whale (Balaenoptera musculus) 20

Odontocetes **20**

Sperm Whale (Physeter macrocephalus) 20

Pygmy and Dwarf Sperm Whales (Kogia spp.) 21

Cuvier's Beaked Whale (Ziphius cavirostris) 22

Northern Bottlenose Whale (Hyperoodon ampullatus) 22

Mesoplodont Beaked Whales 23

Rough-toothed Dolphin (Steno bredanensis) 24

Bottlenose Dolphin (Tursiops truncatus) 25

Pantropical Spotted Dolphin (Stenella attenuata) 25

Atlantic Spotted Dolphin (Stenella frontalis) 26

Spinner Dolphin (Stenella longirostris) 26

Clymene Dolphin (Stenella clymene) 27

Striped Dolphin (Stenella coeruleoalba) 27

Fraser's Dolphin (Lagenodelphis hosei) 27

Short-beaked Common Dolphin (Delphinus delphis) 28

Atlantic White-sided Dolphin (Lagenorhynchus acutus) 28

Risso's Dolphin (Grampus griseus) 28

Melon-headed Whale (Peponocephala electra) 29

Pygmy Killer Whale (Feresa attenuata) 29

False Killer Whale (Pseudorca crassidens) 29

Killer Whale (Orcinus orca) ... 30
Pilot Whales (Globicephala spp.) ... 30
Harbor Porpoise (Phocoena phocoena) ... 31

Pinniped ... 32
Harbor Seal (Phoca vitulina) ... 32
Harp Seal (Phoca groenlandica) ... 32
Gray Seal (Halichoerus grypus) ... 33
Hooded Seal (Cystophora cristata) ... 33

V. TYPE OF INCIDENTAL TAKE AUTHORIZATION REQUESTED ... 33

VI. NUMBERS OF MARINE MAMMALS THAT MAY BE TAKEN ... 34
Marine Mammal Densities ... 34
Sound Exposure Modeling: Acoustic Integration Model (AIM) ... 35
Potential Number of Cetaceans Exposed to Various Received Sound Levels ... 38
Conclusions ... 38

VII. ANTICIPATED IMPACT ON SPECIES OR STOCKS ... 40

Summary of Potential Effects of Airgun Sounds ... 40
Tolerance ... 40
Masking ... 41
Disturbance Reactions ... 41
Hearing Impairment ... 45
Strandings and Mortality ... 50
Non-auditory Physiological Effects ... 51

Possible Effects of Other Acoustic Sources ... 51

VIII. ANTICIPATED IMPACT ON SUBSISTENCE ... 52

IX. ANTICIPATED IMPACT ON HABITAT ... 52

X. ANTICIPATED IMPACT OF LOSS OR MODIFICATION OF HABITAT ON MARINE MAMMALS ... 53

XI. MITIGATION MEASURES ... 53

Planning Phase ... 54

Vessel Strike Avoidance ... 54

Seismic Source Mitigation During Operations ... 54
Proposed Safety Radii ... 55
Pre-Startup Observations ... 55
Ramp-up Procedures ... 56
Speed or Course Alteration ... 56
Power-down Procedures ... 56
Shut-down Procedures ... 57
Passive Acoustic Monitoring ... 57
Chase Vessel ... 57

XII. PLAN OF COOPERATION 58

XIII. MONITORING AND REPORTING PLAN 58

Vessel-based Visual Monitoring 58

PSO Data and Documentation 59

Passive Acoustic Monitoring 60

Reporting 60

XIV. COORDINATING RESEARCH TO REDUCE AND EVALUATE INCIDENTAL TAKE 60

XV. LITERATURE CITED 60

APPENDIX A: MODELING UNDERWATER SOUND FROM A 6420 IN^3 AIRGUN ARRAY 87

APPENDIX B: ACOUSTIC INTEGRATION MODEL (AIM) METHODS 139

APPENDIX C: REVIEW OF THE EFECTS OF AIRGUN SOUNDS ON MARINE MAMMAL 157

Request by ION GeoVentures for an Incidental Harassment Authorization to Allow the Incidental Take of Marine Mammals during a 2-D Seismic Survey off the U.S. East Coast in Summer–Fall 2016

SUMMARY

ION GeoVentures (ION) plans to conduct a 2D marine seismic survey off the U.S. east coast during summer–fall 2016. The planned seismic survey will consist of ~13,062 km of survey lines, most of which (8,561 km) will take place in water depths >1000 m, with less effort in water depths 100–1000 m (2,907 km) and <100 m (1,594 km). Most (6,208 km) of the deep-water survey will be in depths >3000 m. The seismic survey will use a 36-airgun array with a total volume of ~6420 in^3. The purpose of the proposed study is to collect seismic reflection data that reveal the sub-bottom profile as a basis for assessments of petroleum reserves in the area. Ultra-deep 2D lines such as those to be collected are used to better evaluate the evolution of the petroleum system at the basin level, including identifying source rocks, migration pathways, and play types. ION requests that it be issued an Incidental Harassment Authorization (IHA) allowing non-lethal takes of marine mammals incidental to the planned seismic survey. 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 seismic survey will be conducted within and outside of the Exclusive Economic Zone (EEZ) of the U.S.A.

Numerous species of cetaceans occur off the U.S. east coast. Several of these species are listed as ***endangered*** under the U.S. Endangered Species Act (ESA), including humpback, sei, fin, blue, North Atlantic right, and sperm whales. ION is proposing a marine mammal monitoring and mitigation program to minimize the impacts of the proposed activity on marine mammals present during conduct of the proposed research, and to document the nature and extent of any effects.

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 study 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.

Overview of the Activity

ION GeoVentures (ION) plans to conduct a 2D marine seismic survey off the U.S. east coast from ~38.5ºN off Delaware to ~27.9ºN off Florida, and from 20 km from the coast to >600 km from the coast (Fig. 1). The survey will involve one source vessel, the M/V *Discoverer*, and one chase vessel, the M/V *Octopus*, or similar. The seismic source to be deployed from the *Discoverer* is a 36-aigun array with a total volume of 6420 in^3. The survey consists of five widely-spaced transect lines (~20–190 km apart) roughly parallel to the coast and 14 widely-spaced transect lines (~30–220 km apart) in the onshore-offshore direction (Fig. 1) totaling ~13,062 km of survey lines. Most of this effort (~8,561 km) will take place in water depths >1000 m, with less effort in water depths 100–1000 m (~2,907 km) and <100 m (~1,594 km). Most (~6,208 km) of the deep-water survey will be in depths >3000 m. There will be limited additional operations associated with equipment testing, startup, line changes, and repeat coverage of any areas where initial data quality is sub-standard.

The purpose of the proposed study is to collect seismic reflection data that reveal the sub-bottom profile as a basis for assessments of petroleum reserves in the area. Ultra-deep 2D lines such as those to be collected are used to better evaluate the evolution of the petroleum system at the basin level, including identifying source rocks, migration pathways, and play types. This is a privately-funded survey and all planned geophysical data acquisition activities will be conducted by ION GeoVentures. In addition to the airgun array, a low-level acoustic pinger system (operating between 50–100 kHz) may be used to position the 36-airgun array and streamer relative to the vessel, and vessels will operate standard single-beam navigational echosounders.

The vessel will be self-contained, and the crew will live aboard the vessel for the entire cruise. The *Discoverer* will serve as the platform from which vessel-based Protected Species Observers (PSOs) will watch for marine mammals before and during airgun operations. A chase vessel will support the source vessel but will not introduce sounds into the water beyond those associated with normal vessel operations. Helicopter operations are not planned as a part of the seismic survey and would occur only in the case of an emergency.

Vessel Specifications

The geophysical survey will be performed from the M/V *Discoverer* (Fig. 2), a vessel owned by Shanghai Offshore Petroleum Bureau and operated on behalf of ION. The *Discoverer* will tow a 36-airgun array directly astern and a single hydrophone streamer up to 12 km long along predetermined lines (Fig. 1).

The *Discoverer* has a length of 72.1 m, a beam of 16.0 m, and a maximum draft of 6.5 m. The ship is powered by two MLW-ALCO 251 V-12 diesel engines, each producing 2740 hp, which drive the two variable-pitch propellers directly. The vessel also has two Brunvoll bow thrusters (600 hp each). The operation speed during seismic acquisition will be ~4 kt (~7.4 km/h). When not towing seismic survey gear, the *Discoverer* has a cruising speed of 9.5 kt (17.6 km/h) and a maximum speed of 10 kt (~18.5 km/h). The *Discoverer* has a range of ~21,000 km.

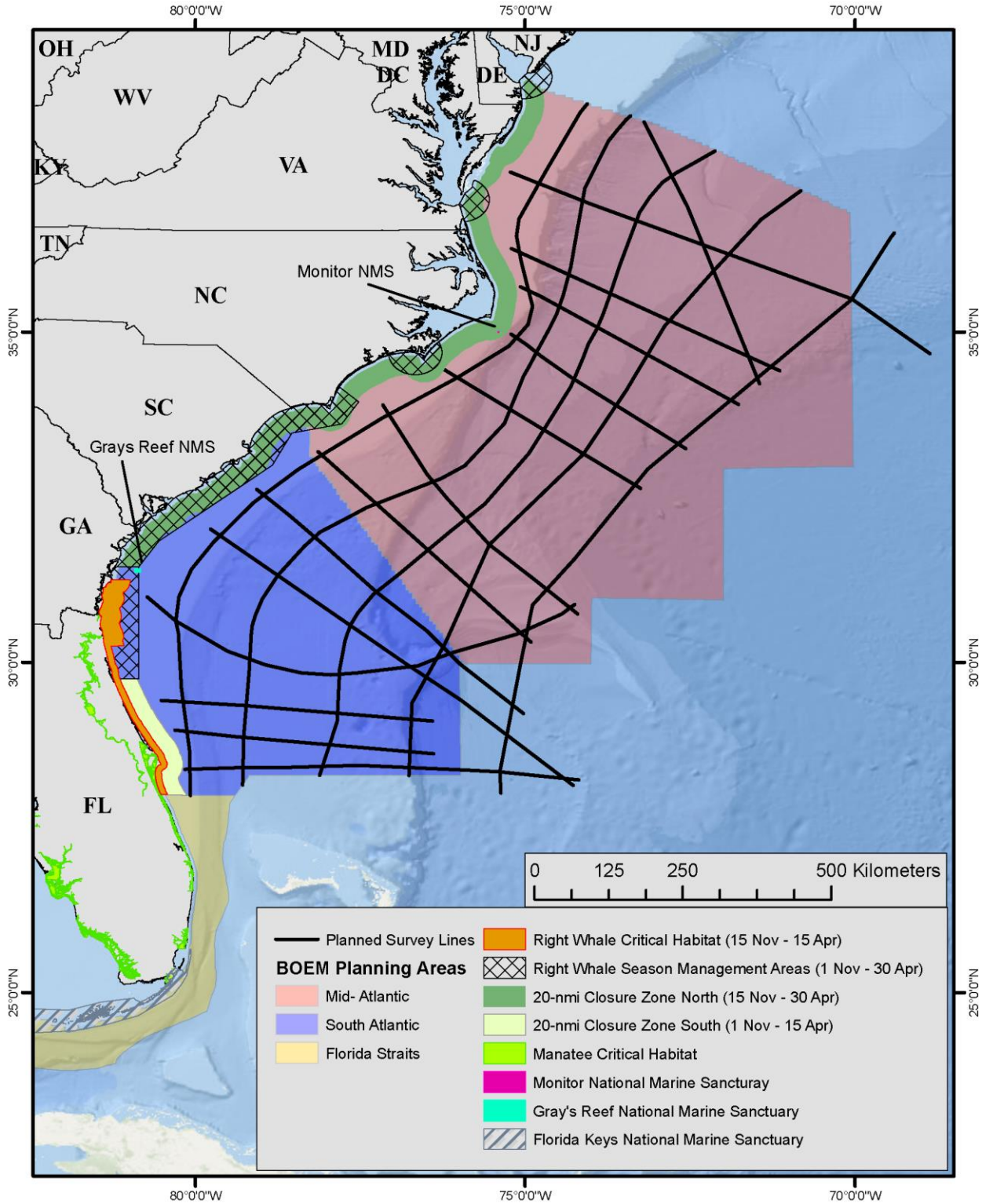

FIGURE 1. Planned seismic survey lines (in black) for ION's proposed seismic survey off the U.S. east coast in 2016.

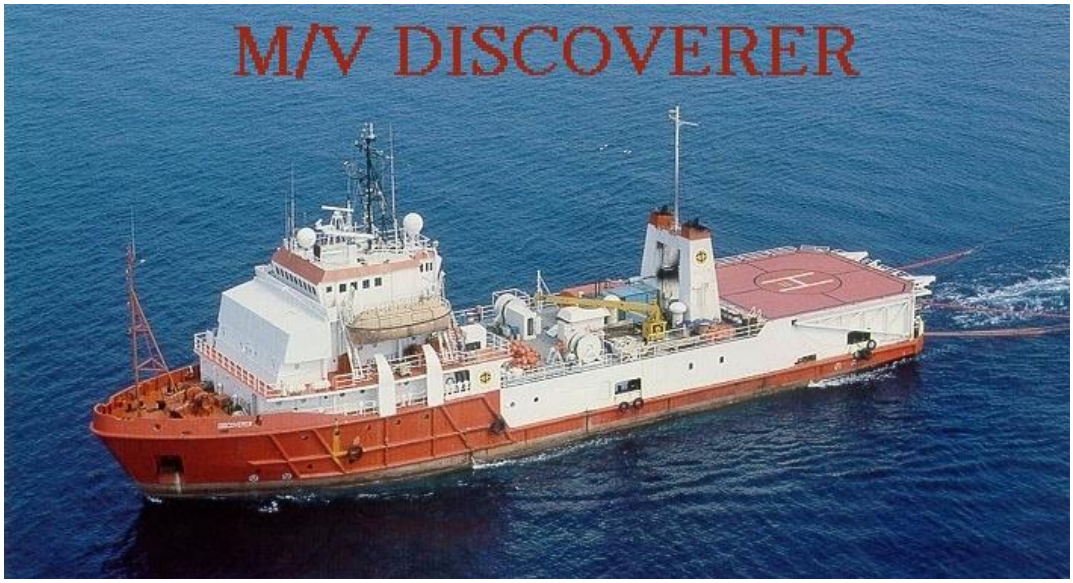

Figure 2. M/V *Discoverer*.

The *Discoverer* will also serve as the platform from which vessel-based protected species observers (PSOs) will watch for animals before and during airgun operations, as described in § XI, below.

Other details of the *Discoverer* include the following:

Owner:	Shanghai Offshore Petroleum Bureau
Flag:	Nassau, Bahamas
Date Built:	1980, converted 1988, refit in 1999
Gross Tonnage:	2747
Accommodation Capacity:	43

A support vessel such as the M/V *Octopus* will be used to protect the streamer from damage and otherwise lend logistical support to the *Discoverer* (e.g., returning to port for fuel, supplies, or any necessary personnel transfers). It will also perform a role in monitoring and mitigation measures (see § XI). The actual support vessel used during the survey will not be determined until a few months ahead of the survey start date.

Airgun Array Description

During the survey, the airgun array to be used will consist of 36 airguns, with a total volume of ~6420 in^3. The array will consist of a mixture of Bolt 1500LL and sleeve airguns ranging in volume from 40 in^3 to 380 in^3; the larger (300–380 in^3) airguns are Bolt airguns, and the smaller (40–150 in^3) airguns are sleeve airguns. The difference between the two types of airguns is in the actual mechnical parts that release the pressurized air; however, the bubble and acoustic energy released by the two types of airguns are effectively the same. The airguns will be configured as four identical linear arrays or "strings" (Fig. 3). Each string will have nine airguns; the first and last airguns in the strings are spaced ~15.5 m apart. The four airgun strings will be distributed across an approximate area of 34×15.5 m behind the *Discoverer* and will be towed ~50–100 m behind the vessel at 10-m depth. The firing pressure of the array is 2000 psi. The airgun array will fire every 50 m or 20–24 s, depending on exact speed. (This is a longer interval than is typical of most industry seismic surveys.) When fired, a brief (~0.1 s) pulse of sound is emitted by all airguns nearly simultaneously. The airguns will be silent during the intervening periods.

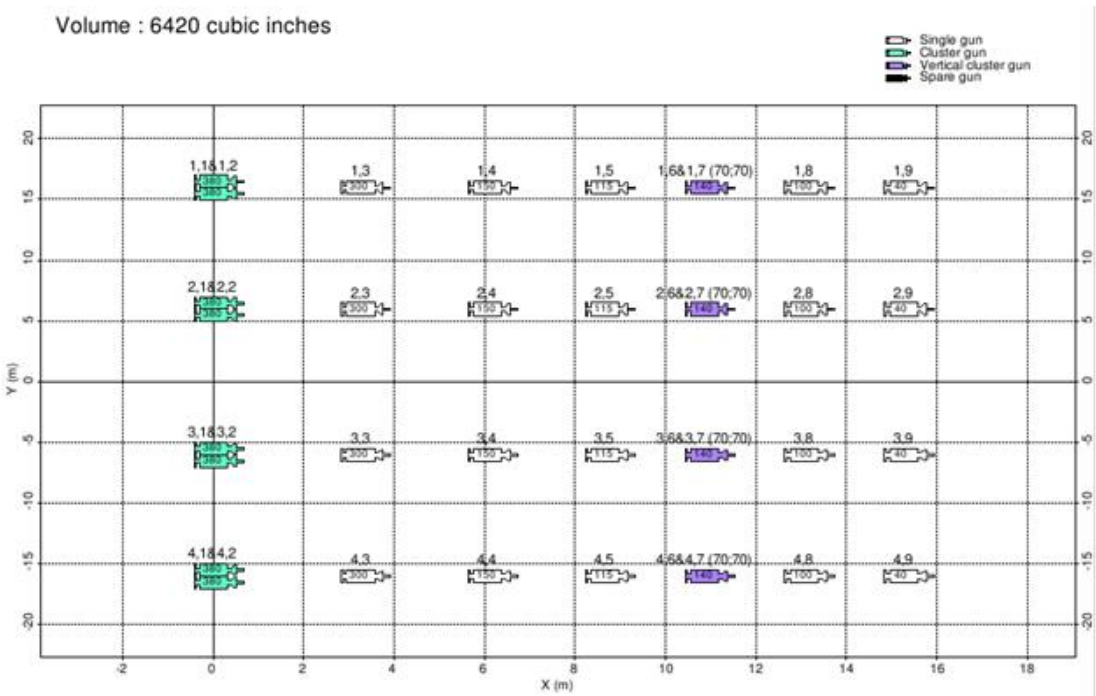

Figure 3. Layout of the R/V *Discoverer*'s 6420-in^3 airgun array. Symbol sizes and labels indicate the volumes of the airguns in cubic inches. Tow direction is to the left.

Because the actual source is a distributed sound source (36 airguns) rather than a single point source, the highest sound levels measurable at any location in the water will be less than the nominal source level. In addition, the effective source level for sound propagating in near-horizontal directions will be substantially lower than the nominal source level applicable to downward propagation because of the directional nature of the sound from the airgun array. The horizontal propagation of sound is reduced by noise cancellation effects created when sound from neighboring airguns on the same horizontal plane partially cancel each other out.

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

Energy Source	Thirty-six 2000 psi airguns of 40–380 in^3, in four strings each containing nine operating airguns
Source output (downward)	0-pk = 68.3 bar-m (257 dB re 1 μPa·m); pk-pk = 147.1 bar·m (263 dB re 1 μPa·m); rms = approximately 254 dB re 1 μPa·m
Towing depth of energy source	10 m
Air discharge volume	~6420 in^3
Dominant frequency components	<175 Hz

Airgun Array Source Signature

The array was modeled using the JASCO Research's airgun array source signature model to compute notional source signatures and also 1/3-octave band source levels as a function of azimuth angle (see Appendix A for a description of the model). The resulting broadside and endfire (relative to the trackline) overpressure signatures and corresponding power spectrum levels are shown in Figure 4. Horizontal 1/3-octave band directionality plots are shown in Figure 5.

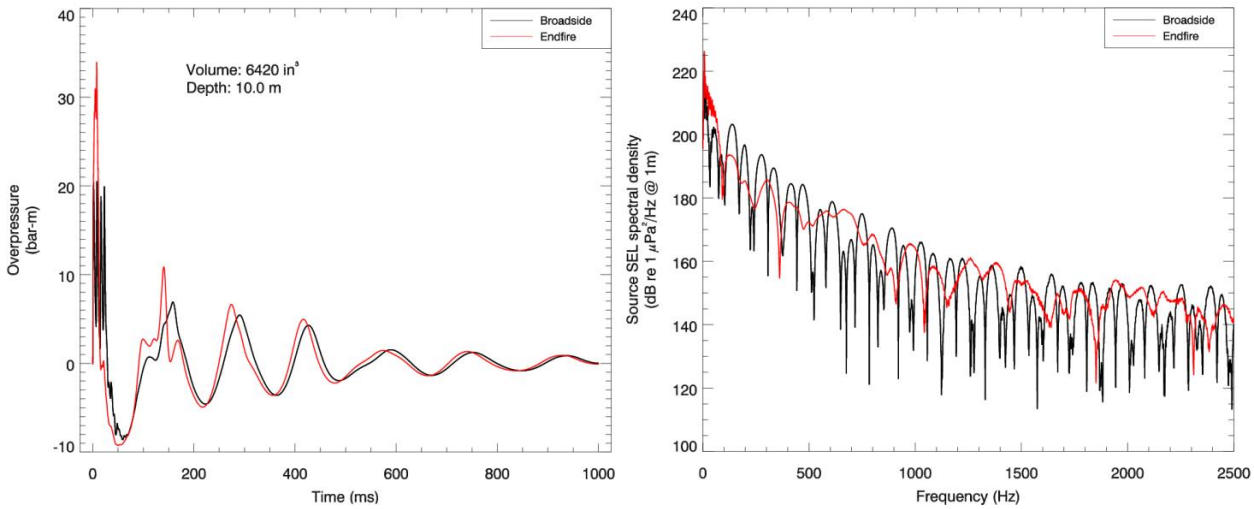

Figure 4. Predicted broadside and endfire overpressure signatures, with associated frequency spectra, for the 6420-in^3 array. "Broadside" means to the side of the trackline and "endfire" is along the trackline.

Sound Propagation Model

Received sound levels have been modeled for the 36-airgun array in relation to distance and direction from the airguns at 18 sites in the survey area (see Appendix A). Two of the modeling sites are were located off the coast of sourthern Florida along survey lines that are not included in this requeston. The maximum relevant depth (2000 m) is the maximum assumed dive depth for deep-diving marine mammals and is relevant for predicting safety radii. JASCO's propagation model is based on an implementation of the widely-used Range-dependent Acoustic Model (RAM), with enhancements (see Appendix A). It takes into account the water depth, bottom topography, seabed geoacoustics, anticipated sound-speed profile (SSP), as well as the tow depth of the array. SSPs for the months of August and December were selected as they represent the worst and best propagation scenarios, respectively, for the survey period. A detailed description of the modeling methods is provided in Appendix A.

The predicted sound contours are shown as sound pressure levels (SPL) in decibels (dB) re 1 μPa_{rms} for four example sites covering water depths from 30 m to 4300 m (Fig. 6). Although SEL, a measure of the received energy in the pulse, is now believed to be a better measure than SPL when dealing with biological effects of pulsed sound (Southall et al. 2007), SPL is the measure that has been used most commonly in studies of marine mammal behavioral reactions to airgun sounds and remains the current NMFS guidelines concerning levels above which Level-B "taking" might occur.

It should be noted that neither the SEL nor the SPL (= rms) measure is directly comparable to the peak or peak-to-peak pressure levels normally used by geophysicists to characterize source levels of airguns. Peak and peak-to-peak pressure levels for airgun pulses are always higher than the rms dB referred to in much of the biological literature (Greene 1997; McCauley et al. 1998, 2000). For example, a measured received level of 160 dB re 1 μPa_{rms} in the far field would typically correspond to a peak measurement of ~170–172 dB re 1 μPa, and to a peak-to-peak measurement of ~176–178 dB re 1 μPa, as measured for the same pulse received at the same location (Greene 1997; McCauley et al. 1998, 2000). The SEL value for the same pulse would normally be 145–150 dB re 1 $\mu Pa^2 \cdot s$. The precise difference between rms and peak or peak-to-peak values for a given pulse depends on the frequency content and duration of the pulse, among other factors. However,

for an airgun-type source, the rms level is always lower than the peak or peak-to-peak level and (at the ranges relevant here) higher than the SEL value.

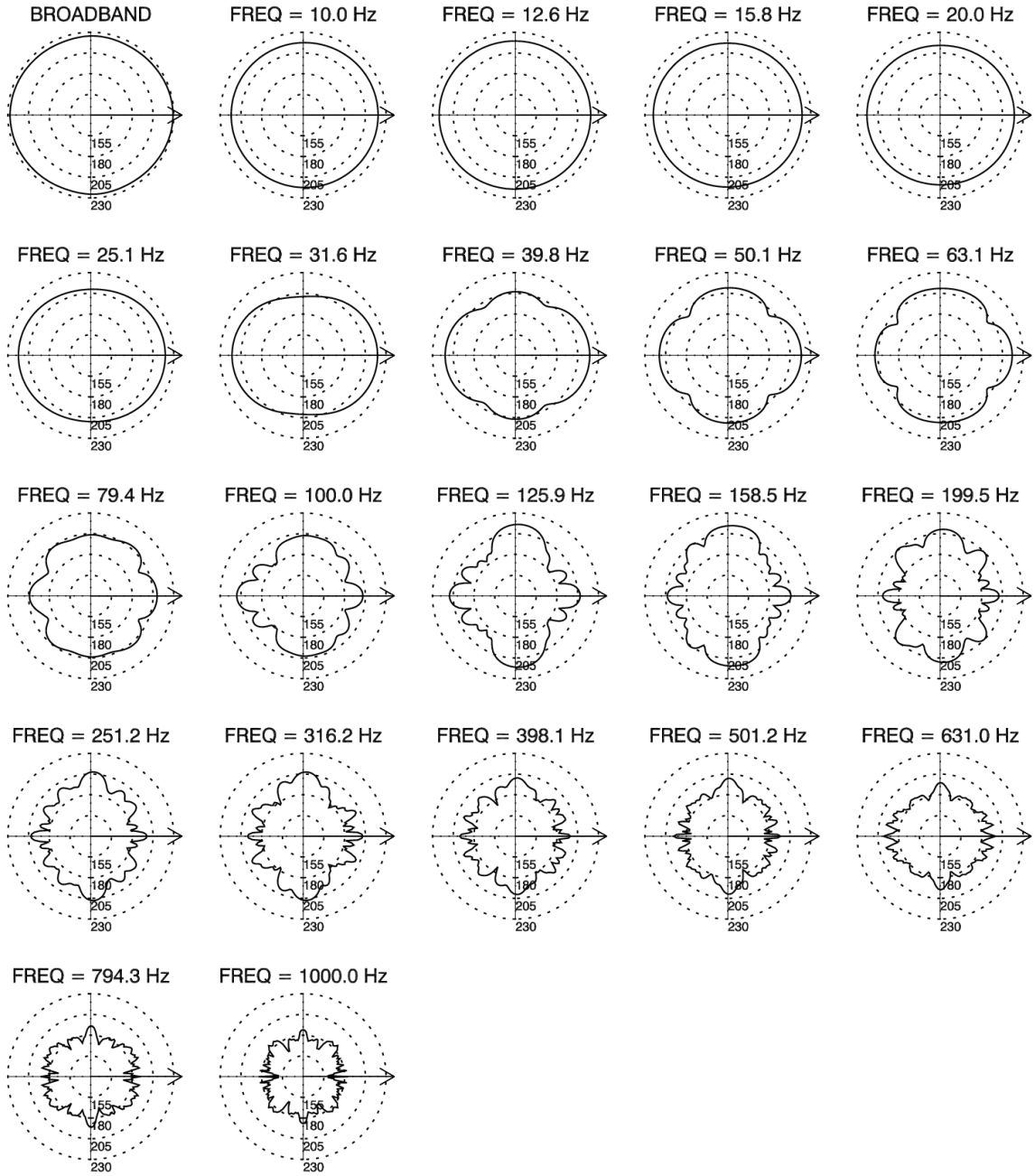

Figure 5. Directionality of the predicted airgun array sound energy levels (SELs) in dB re 1 $\mu Pa^2 \cdot s$ for the 6420-in^3 array at 10-m tow depth, in 1/3-octave bands with center frequencies from 10 Hz to 1 kHz. Tow direction is toward the right. Band center frequencies are indicated in the plot annotation.

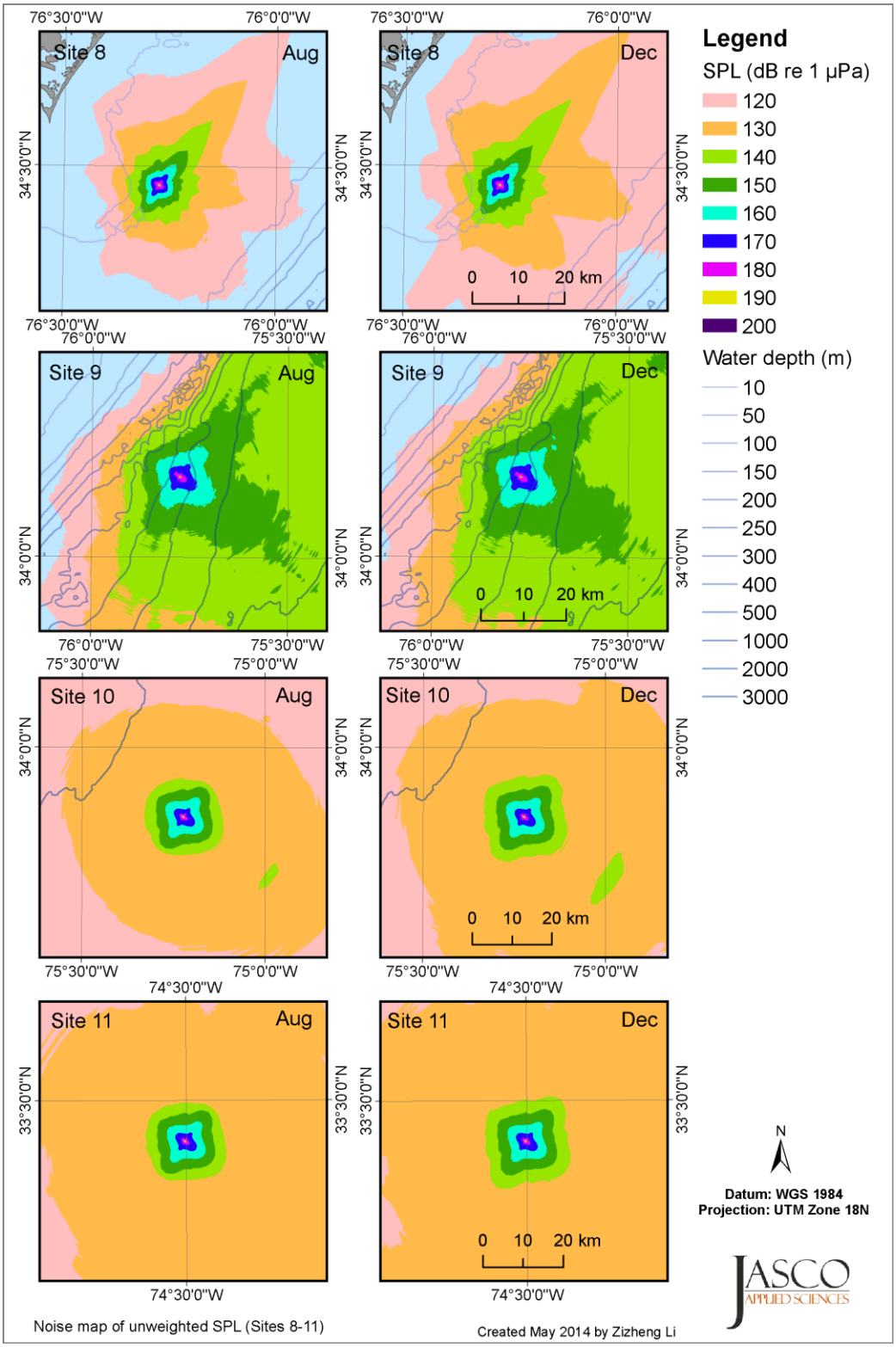

Figure 6. Contours of estimated rms SPL (dB re 1 µPa) produced by the 6420 in^3 array at sites 8-11 in August and December. Water depths at the sites are: Site 8 = 30 m, Site 9 =700, Site 10 = 3300 m, Site 11 = 4200 m. Tow direction is 126° in all cases. Panels on the left are for August and panels on the right are for December.

Table 1 shows the maximum distances at which four flat-weighted rms sound levels are expected to be received from the 36-airgun array in three different water depths. For comparison, the 180-dB re 1 $\mu Pa^2 \cdot s$ distances are also given using the M-weighting function for mid-frequency cetaceans (M_{mf}-weighted), which takes into account the frequencies at which most toothed whales are most sensitive. The distances based on flat-weighted sound levels are the safety criteria as specified by NMFS (2000) for all cetaceans. That is reasonable for baleen whales, because their hearing is best at the low frequencies that are dominant in airgun sound, so the planned 180-dB safety radii will be based on the flat-weighted rms sound levels. However, because toothed whales are less sensitive to those low-frequency sounds, it is a cautionary approach for those species.

During reduced power operations, such as turns between survey lines, during brief equipment maintenance, or power downs for marine mammals observed within the exlusion zone of the full airgun array, a single 40 in^3 airgun (approximate source level of 217 dB re 1 µPa SPL rms) will continue operating. BOEM (2014a) included acoustic propagation modeling results for a 2-airgun, 90 in^3 source that showed the expected 180-dB re 1 μPa_{rms} distance to be between 74 m and 177 m, depending on season and location. Measurements of a 4x10 in^3 array were made at various locations offshore Alaska and distances to the 180-dB re 1 μPa_{rms} threshold ranged from 99 m to 160 m (NOAA 2013a). A single airgun of 40 in^3 will have a smaller acoustic footprint than either of the two sources described above, but as a cautionary approach, a 150-m exclusion zone will be enforced around the single operating 40 in^3 airgun.

Detailed recommendations for new science-based noise exposure criteria were published by Southall et al. (2007) and NMFS has recently released draft guidelines reflecting those recommendations as well as more recent data on marine mammal hearing (NOAA 2013b). ION will be prepared to incorporate finalized guidelines during the permitting process, at the direction of NMFS.

Table 1. Largest predicted distances to which flat-weighted sound pressure levels ≥190, 180, 170, and 160 dB re 1 μPa_{rms} and M_{mf}-weighted (for mid-frequency cetaceans) sound exposure levels ≥180 dB re 1 $\mu Pa^2 \cdot s$ could be received in shallow (<100 m), intermediate (100–1000 m), and deep (>1000 m) water from the 6420 in^3 36-airgun array planned for use during the proposed seismic survey in summer (July–September) and fall (October–December) 2016 (Appendix A).

		SEL M_{mf}-weighted	**$R_{95\%}$ rms Flat-weighted Radii (km)**			
Season	**Water Depth**	**180 dB**	**190 dB**	**180 dB**	**170 dB**	**160 dB**
Summer	Deep	0.08	0.44	1.88	3.62	7.53
	Intermediate	0.08	0.44	1.71	3.96	8.21
	Shallow	0.12	0.47	1.11	2.39	4.74
Fall	Deep	0.08	0.44	1.89	3.59	7.48
	Intermediate	0.08	0.45	1.72	3.97	8.25
	Shallow	0.11	0.48	1.12	2.57	5.27

II. DATES, DURATION, AND REGION OF ACTIVITY

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

ION plans to conduct the 2D seismic survey from July through December of 2016. The survey area is off the U.S. east coast from ~38.5ºN off Delaware to ~27.9ºN off Florida, and from 20 km from the coast to >600 km from the coast (Fig. 1). It is expected that seismic data collection using the full airgun array would require ~70 days to complete and that survey overall survey activities would take ~100 days.

III. SPECIES AND NUMBERS OF MARINE MAMMALS IN AREA

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

Thirty-nine species of marine mammals, comprised of 27 odontocetes, 7 mysticetes, 4 pinnipeds and the West Indian manatee, could occur in the proposed survey area, based on historical and more recent surveys of marine mammal surveys by ship and aircraft off the U.S. east coast conducted by NMFS-SEFSC (Southeast Fisheries Science Center), NMFS-NEFSC (Northeast Fisheries Science Center), URI (University of Rhode Island), MBO (Manomet Bird Observatory), and UNCW (University of North Carolina–Wilmington). Except for the West Indian manatee, all marine mammal species in the proposed survey area fall under the jurisdiction of the NMFS. The West Indian manatee is listed as ***endangered*** under the ESA, and critical habitat has been designated for this species in the Intracoastal Waterway, seagrass beds, lagoons, and bays along Florida's east coast (USFWS 1976). As the West Indian manatee falls under the jurisdiction of the USFWS, it will not be discussed further.

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

Sections III and IV are integrated here to minimize repetition.

Thirty-eight species of marine mammals that are under the jurisdiction of NMFS could occur in the proposed survey area. Six of these species are listed as ***endangered*** or ***threatened*** under the ESA, including the North Atlantic right, humpback, sei, fin, blue, and sperm whales (Table 2). The stocks of two other species are considered to be strategic under the MMPA: the Gulf of Maine/Bay of Fundy harbor porpoise and five stocks of coastal bottlenose dolphins in the Western North Atlantic, which are also designated as depleted under the MMPA. In addition, critical habitat has been designated for the North Atlantic right whale, including waters adjacent to the coasts of Georgia and the east coast of Florida (NMFS 1994).

In § 4.2.2 of the PEIS, BOEM (2014a) provided information on the status, distribution, behavior and auditory and vocalization range of marine mammals occurring in the western North Atlantic Ocean. Information on the occurrence in the proposed survey area in July–December, habitat, population size, and conservation status for each of the marine mammal species that could occur in the proposed survey area is presented in Table 2. The following text contains descriptions of all other marine mammal species, and summarizes what is known about habitat use and spatial and temporal distribution in the proposed survey area.

TABLE 2. The habitat, occurrence, and conservation status of marine mammals that could occur in or near the proposed survey area in the northwestern Atlantic Ocean.

Species	**Occurrence in Mid-Atlantic/ Southern Portion of Survey Area July–Dec[1]**	**Habitat**	**Regional Population[2]**	**U.S. ESA[3]**	**MMPA Status[4]**
Mysticetes North Atlantic right whale (*Eubalaena glacialis*)	Reg/Reg	Inshore, occasionally offshore	455	EN	Strategic
Humpback whale (*Megaptera novaeangliae*)	Reg/Reg	Nearshore, banks, offshore when migrating	823[5]; 11,570[6]	EN	Strategic
Minke whale (*Balaenoptera acutorostrata*)	Reg/Reg	Coastal	20,741[7]	NL	Not strategic
Bryde's whale (*Balaenoptera edeni*)	Rare/Rare	Offshore, coastal	N.A.	NL	Strategic[8]
Sei whale (*Balaenoptera borealis*)	Rare/Rare	Mostly offshore	357[9]; 2078[10]	EN	Strategic
Fin whale (*Balaenoptera physalus*)	Reg/Reg	Mostly offshore, slope	3522	EN	Strategic
Blue whale (*Balaenoptera musculus*)	Rare/Rare	Offshore, coastal	400-600[11]	EN	Strategic
Odontocetes Sperm whale (*Physeter macrocephalus*)	Reg/Reg	Usually offshore	2288[12] 13,190[13]	EN	Strategic
Pygmy sperm whale (*Kogia breviceps*)	Reg/Reg	Deep waters off shelf	3785[14]	NL	Not strategic

Species	Occurrence in Mid-Atlantic/ Southern Portion of Survey Area July–Dec[1]	Habitat	Regional Population[2]	U.S. ESA[3]	MMPA Status[4]
Dwarf sperm whale (*Kogia sima*)	Rare/Reg	Deep waters off shelf	3785[14]	NL	Not strategic
Cuvier's beaked whale (*Ziphius cavirostris*)	Reg/Reg	Offshore	6532	NL	Not strategic
Northern bottlenose whale (*Hyperoodon ampullatus)*	Ex/Ex	Offshore	N.A.	NL	Not strategic
True's beaked whale (*Mesoplodon mirus)*	Reg/Ex	Offshore	7092[15]	NL	Not strategic
Gervais' beaked whale (*Mesoplodon europaeus)*	Reg/Reg	Offshore	7092[15]	NL	Not strategic
Sowerby's beaked whale (*Mesoplodon bidens*)	Rare/Rare	Offshore	7092[15]	NL	Not strategic
Blainville's beaked whale (*Mesoplodon densirostris*)	Reg/Reg	Offshore	7092[15]	NL	Not strategic
Rough-toothed dolphin (*Steno bredanensis*)	Reg/Reg	Mostly offshore	271	NL	Not strategic
Common bottlenose dolphin (*Tursiops truncatus*)[16]	Reg/Reg	Outer shelf, slope	77,532[17]	NL	Not strategic
Common bottlenose dolphin (*Tursiops truncatus*)[16]	Reg/Reg	Coastal	31,212[18]	NL	Strategic & depleted
Pantropical spotted dolphin (*Stenella attenuata*)	Reg/Reg	Mostly offshore	3333	NL	Not strategic
Atlantic spotted dolphin (*Stenella frontalis*)	Reg/Reg	Offshore, shelf	44,715	NL	Not strategic
Spinner dolphin (*Stenella longirostris*)	Reg/Reg	Offshore, coastal	N.A.	NL	Not strategic
Clymene dolphin (*Stenella clymene*)	Reg/Reg	Offshore	6086[19]	NL	Not strategic
Striped dolphin (*Stenella coeruleoalba*)	Reg/Reg	Shelf, slope	54,807	NL	Not strategic
Fraser's dolphin (*Lagenodelphis hosei*)	Ex/Reg	Deep waters off shelf	N.A.	NL	Not strategic
Short-beaked common dolphin (*Delphinus delphis*)	Reg/Reg	Shelf, offshore	173,486	NL	Not strategic
Atlantic white-sided dolphin (*Lagenorhynchus acutus*)	Rare/Ex	Shelf, slope	48,819	NL	Not strategic
Risso's dolphin (*Grampus griseus*)	Reg/Reg	Shelf, slope, seamounts	18,250	NL	Not strategic
Melon-headed whale (*Peponocephala electra*)	Ex/Reg	Offshore	N.A.	NL	Not strategic
Pygmy killer whale (*Feresa attenuata*)	Rare/Reg	Offshore	N.A.	NL	Not strategic
False killer whale (*Pseudorca crassidens*)	Rare/Reg	Offshore, occasionally inshore	N.A.	NL	Not strategic
Killer whale (*Orcinus orca*)	Reg/Reg	Widely distributed	N.A.	NL	Not strategic
Long-finned pilot whale (*Globicephala macrorhynchus*)	Reg/Ex	Mostly offshore, high-relief topography	26,535	NL	Not strategic
Short-finned pilot whale (*Globicephala melas*)	Reg/Reg		21,515	NL	Not strategic
Harbor porpoise (*Phocoena phocoena*)	Rare/Ex	Coastal, inland waters	79,883[20]	NL	Strategic
Pinnipeds Gray seal (*Halichoerus grypus*)	Ex/Ex	Coastal	N.A.	NL	Not strategic
Harbor seal (*Phoca vitulina*)	Rare/Ex	Coastal	70,142	NL	Not strategic
Harp seal (*Phoca groenlandica*)	Ex/Ex	Pack ice, coastal	N.A.	NL	Not strategic
Hooded seal (*Cystophora cristata*)	Ex/Ex	Pack ice, offshore	N.A.	NL	Not strategic

N.A. = Data not available.
[1] Frequency of occurrence categories based on DoN (2007a,b, 2008a,b,c): Reg(ular) = a species that occurs as a regular or normal part of the fauna of an area regardless of its abundance; Rare = a species that only occurs in an area sporadically; Ex(tralimital) = a species that does not normally occur in an area and occurrence is considered to be beyond the normal range of the species even though one or more occurrence records exist.
[2] Regional best population estimates are for the U.S. EEZ from Waring et al. (2014), unless otherwise noted.
[3] U.S. Endangered Species Act (NMFS 2015a): EN = Endangered, NL = Not Listed.
[4] MMPA status from Waring et al. (2014).
[5] Gulf of Maine stock.
[6] North Atlantic stock during 1992/1993 (Stevick et al. 2003).
[7] Canadian East Coast stock.
[8] Gulf of Mexico stock is considered strategic.
[9] Nova Scotia stock.
[10] Western North Atlantic stock (Mitchell and Chapman 1977).
[11] Western North Atlantic (R. Sears, pers. comm. *in* Waring et al. 2011).
[12] North Atlantic stock.
[13] North Atlantic (Whitehead 2002).
[14] Estimate includes both dwarf and pygmy sperm whales.
[15] Estimate includes 149 Gervais' and 149 Blainville's beaked whales in the Gulf of Mexico and all *Mesoplodon* spp. in the Atlantic.
[16] The Biscayne Bay, Floriday Bay, and eight estuarine system stocks are not expected to be affected by the proposed acvities.
[17] Western North Atlantic Offshore stock, may include sightings of coastal form.
[18] Sum of five coastal stocks: Northern Migratory (11,548 animals), Southern Migratory (9173), South Carolina/Georgia (4377), Northern Florida (1219), and Central Florida Coastal stock (4895).
[19] Abundance estimate is from 1998; thus, it is considered unreliable by Waring et al. (2014), because estimate is >8 years old. .
[20] Gulf of Maine/Bay of Fundy.

Mysticetes

North Atlantic Right Whale (*Eubalaena glacialis*)

The North Atlantic right whale population is one of the world's most critically endangered large whale populations (Clapham et al. 1999; IWC 2001). Historically, right whale populations were severely depleted by commercial whaling. More recently, lack of recovery in the population has been attributed to direct and indirect impacts from human activities, especially ship collisions and fishing gear entanglements (IWC 2001; Waring et al. 2014). A recovery plan has been in place since 1991; this plan was most recently revised in 2005 (NMFS 2005a).

The North Atlantic right whale is known to occur primarily in the continental shelf waters off the eastern U.S. and Canada, from Florida to Nova Scotia (Winn et al. 1986; Jefferson et al. 2008). However, the range of the population extends from as far north as southeast of Greenland, Iceland, and Norway to as far south as the Gulf of Mexico, including off Texas, where a cow/calf pair was sighted (Moore and Clarke 1963; Winn et al. 1986; Knowlton et al. 1992; IWC 2001; NEAQ 2006).

There are six major habitats or congregation areas used annually by western North Atlantic right whales (Winn et al. 1986; NMFS 2005a; Waring et al. 2014): (1) winter calving grounds in coastal waters of the southeastern U.S. (Florida/Georgia); (2) spring feeding grounds in the Great South Channel (east of Cape Cod); (3) late winter/spring feeding grounds and nursery grounds in Massachusetts Bay and Cape Cod Bay; (4) spring feeding grounds in Georges Bank/Gulf of Maine; (5) summer/fall feeding and nursery grounds in the Bay of Fundy; and (6) summer/fall feeding grounds on the Nova Scotian Shelf. The first three areas have been designated as critical habitat for North Atlantic right whales (NMFS 1994). The nearest planned survey line is, at it's closest point, ~27 km from the North Atlantic right whale southeast U.S. critical habitat area in coastal waters of Georgia and Florida.

Recent evidence suggests that the Gulf of Maine may also be important habitat as a mating ground in winter (Cole et al. 2013). In addition, Jeffreys Ledge, off the coast of northern Massachusetts, New

Hampshire, and Maine could be an important fall feeding area for right whales and an important nursery area during summer, especially in July and August (Weinrich et al. 2000). Movements between and within the six habitats are extensive (Waring et al. 2014). There is a general seasonal north-south migration between feeding and calving areas, but right whales could be seen anywhere off the Atlantic U.S. coast throughout the year (Gaskin 1982). The migration route between the Cape Cod summer feeding grounds and the Georgia/Florida winter calving grounds, known as the mid-Atlantic corridor, has not been included as a "high use" area, yet whales move through these waters regularly in all seasons (Reeves and Mitchell 1986; Winn et al. 1986; Kenney et al. 2001; Reeves 2001; Knowlton et al. 2002).

Mid-Atlantic coastal area.—The seasonal occurrence of right whales in mid-Atlantic waters is mostly between November and April, with peaks in December and April (Winn et al. 1986) when whales transit through the area on their migrations between breeding and feeding grounds. North Atlantic right whales are found commonly on the northern feeding grounds off the northeastern U.S. during early spring and summer. Throughout the remainder of summer and into fall (June–November), they are most commonly seen farther north on feeding grounds in Canadian waters, with a peak abundance during August, September, and early October (Gaskin 1987).

Some whales, including mothers and calves, remain on the feeding grounds through the fall and winter. However, the majority of the right whale population leaves the feeding grounds for unknown wintering habitats and returns the following spring. Though many right whales are sighted along the Florida/Georgia winter calving ground, the majority of the right whale population is unaccounted for, and not all reproductively-active females return to the southeast coast each year (Kraus et al. 1986; Winn et al. 1986; Kenney et al. 2001). Other wintering areas have been suggested, based on sparse data or historical whaling logbooks; these include the Gulf of St. Lawrence, Newfoundland and Labrador, coastal waters of New York and between New Jersey and North Carolina, Bermuda, and Mexico (Payne and McVay 1971; Aguilar 1986; Mead 1986; Lien et al. 1989; Knowlton et al. 1992; Patrician et al. 2009). More recently, Morano et al. (2012) and Mussoline et al. (2012) indicated that right whales are present in the southern Gulf of Maine year-round and that they occur there over longer periods than previously thought. Using aerial survey data collected during 2002–2008, Cole et al. (2013) identified half of the North Atlantic population in the central Gulf of Maine between November and January.

Knowlton et al. (2002) prepared an extensive and detailed analysis of survey data, satellite tag data, whale strandings, and opportunistic sightings along U.S. coastal waters of the mid-Atlantic migratory corridor[1], from the Georgia/South Carolina border north to 41°20'N and west of 69°45'W. The majority of sightings (94%) along the migration corridor were within 56 km of shore, and more than half (64%) were within 18.5 km of shore (Knowlton et al. 2002). Most sightings >56 km offshore occurred at the northern end of the corridor, off New York and south of New England. Water depth preference was for shallow waters; 80% of all sightings were in depths <27 m and 93% of sightings were in depths <45 m (Knowlton et al. 2002). A relatively small number of right whale sightings were made year-round along the coast between Cape Hatteras a Rhode Island; these mid-Atlantic sightings peaked in April, May, and September (Knowlton et al. 2002). The Interactive North Atlantic Right Whale Sightings Map showed 12 or fewer sightings per month during July–December off the coasts of Virginia, Maryland, and Delaware, combined (NEFSC 2014).

[1] Multi-year datasets for the analysis were provided by the New England Aquarium (NEAQ), North Atlantic Right Whale Consortium (NARWC), Oregon State University, Coastwise Consulting Inc, Georgia Department of Natural Resources, University of North Carolina W (UNCW), Continental Shelf Associates, Cetacean and Turtle Assessment Program (CETAP), National Oceanic and Atmospheric Administration (NOAA) and University of Rhode Island (URI).

Southern coastal area.—Pregnant females and some juveniles migrate to the calving grounds through the coastal waters off North Carolina, Georgia, and northern Florida during late autumn and winter, generally arriving between November and March (Winn et al. 1986; Kraus et al. 1986; Kenney et al. 2001). Right whales on their winter calving grounds are most often found near the coast in ~10 m water depths (Kraus et al. 1988). The distribution of calving right whales off Florida and Georgia is highly correlated to water temperatures of 13–15ºC and water depths of 15–20 m (Garrison 2005; Keller et al. 2006). In winter, many right whales are found in the currently defined boundary of the critical habitat, but high densities of whales have been found to the north of the designated critical habitat in response to inter-annual variability in the water temperature (Keller et al. 2006).

Knowlton et al. (2002) reported that peak sightings between Cape Hatteras and northern Georgia (north of the critical habitat) occurred from February to April. At Cape Hatteras, whales were sighted during December–February, with a pulse of sightings in February and March. Whales further south in the vicinity of Wilmington, North Carolina, were seen during October–April, and sightings off South Carolina occurred during October–May. Sightings off Savannah, Georgia, occurred during November–May, with peak abundance in the area during December–March. No sightings occurred between Cape Hatteras and northern Georgia during June–August, and only a "few" occurred in September; however effort rating was "light" in all four months (Knowlton et al. 2002).

Off the coast of Florida, right whales are generally seen from November to March, although a few have been reported as early as September and as late as June in some years (Kraus et al. 1993). On 17 July 2007, one cow/calf pair was reported ~25 km east of Mayport, Florida (NOAA 2007).

The distribution of sightings relative to the shore in the southern coastal survey area was similar to the mid-Atlantic coastal area; most right whales were sighted in shallower waters close to shore, and few were seen offshore. The majority of whales were sighted within 28–38 km from shore (Knowlton et al. 2002). The Interactive North Atlantic Right Whale Sightings Map showed an increase in monthly sightings from July–December off the coasts of Florida through North Carolina, combined; there were 5 sightings in July, 0 in August, 7 in September, 22 in October, 56 in November, and 919 in December (NEFSC 2014). There were 11 and 443 sightings off the Florida coast in November and December, respectively. These were generally all north of Cape Canaveral, with the southernmost sighting off Boynton Beach in December 1992 (NEFSC 2014).

Offshore area.—Right whale sightings in deep, offshore waters of the western North Atlantic are rare. There is some, but limited evidence suggesting that there could be a regular offshore component of their distribution:

- The majority of the population (except for mother/calf pairs and some adult females and juveniles) is absent from most coastal habitats in winter (Winn et al. 1986; Kraus et al. 1986; Kenney et al. 2001).
- Genetic and sighting data indicate that some females consistently take their calves to other, undiscovered summer grounds (Schaeff et al. 1993).
- There are occasional offshore sightings off the mid-Atlantic states and off southeastern U.S. (EWS 1997–2007; Knowlton et al. 2002; Niemeyer 2007, 2008).
- One of nine right whales satellite-tagged in the Bay of Fundy in September 1990 moved offshore for seven days, spending time at the edge of a warm core ring (Mate et al. 1997).
- An entangled pregnant female off Jacksonville, Florida, was satellite-tracked in January 1996 to nearly the middle of the Atlantic Ocean, where it remained for a period of months (WhaleNet 1998).

- A right whale calf birth was observed 63 km offshore from Jacksonville, Florida, in March 2010 (Foley et al. 2011).

The Interactive North Atlantic Right Whale Sightings Map showed very few offshore sightings during July–December: there were three sightings in July, two sightings per month in August and September, one sighting in each of October and November, and no sightings in December (NEFSC 2014). However, the occurrence of right whales in the offshore area between July and December is unknown given that survey effort is low in offshore waters at any time of year (Waring et al. 2014).

Federal and other action.—In 2002, NMFS received a petition to revise and expand the designation of critical habitat for the North Atlantic right whale. The revision was declined, and the critical habitat designated in 1994 remained in place (NMFS 2005a). Another petition for a revision to the critical habitat was received in 2009 that sought to expand the currently designated critical feeding and calving habitat areas and include a migratory corridor as critical habitat (NMFS 2010). In February 2015, NMFS (2015b) proposed to expand the designated critical habitat and replace the existing two areas with two new larger ones . The designation of critical habitat does not restrict activities within the area or mandate any specific management action. However, actions authorized, funded, or carried out by Federal agencies that may have an impact on critical habitat must be consulted upon in accordance with Section 7 of the ESA, regardless of the presence of right whales at the time of impacts. Impacts on these areas that could affect primary constituent elements such as prey availability and the quality of nursery areas must be considered when analyzing whether habitat may be adversely modified.

A number of other actions taken to protect North Atlantic right whales include the following:

- Establishment of the Right Whale Sighting Advisory System (RWSAS; see NEFSC 2012) designed to reduce collisions between ships and right whales by alerting mariners to the presence of the whales.
- A Mandatory Ship Reporting System implemented by the U.S. Coast Guard (USCG) in right whale nursery and feeding areas (USCG 1999, 2001; Ward-Geiger et al. 2005). Mandatory ship reporting takes place in the southeastern U.S. during 15 November – 16 April of the following year. The geographical boundaries of the area include coastal waters within ~45 km of shore along a 170-km stretch of the Atlantic coast in Florida and Georgia.
- Establishment of recommended shipping routes in key right whale aggregation areas off the ports of Jacksonville and Fernandina Beach, Florida, and Brunswick Harbor, Georgia (NOAA 2006, 2014a).
- Regulations to implement seasonal mandatory vessel speed restriction of 10 knots (~18.5 km/h) or less in specific locations (seasonal management areas; SMA) along the U.S. east coast during times when whales are likely present. Speed restrictions apply to all vessels greater than or equal to 65 ft (~20 m) in length. Speed restrictions extend out to 20 n.mi. (~37 km) around the major ports and sections of the coast along the mid-Atlantic corridor during 1 November – 30 April, and around calving and nursery grounds off Florida and Georgia during 15 November – 15 April (NMFS 2008). None of the proposed seismic survey lines fall within SMAs.
- Establishment of dynamic management areas (DMA) for reliable sightings of right whales in specific areas (e.g., a designated shipping lane or port entrance) outside the SMA. Vessel speed restrictions (10 knots) within DMAs are voluntary (NMFS 2006, 2008) and are typically in place for 7–14 days.

- As part of the Atlantic Large Whale Take Reduction Plan (ALWTRP), NMFS established broad-based fishing gear modifications to traps, pots, and gillnets. These gear requirements were in place by April 2009 and replaced the use of dynamic area management (DAM) zones, which were established in response to reliable reports of unexpected right whale aggregations in areas north of 40°N. DAM zones also required gear modifications and were employed during 2002–2009 (NOAA 2012).

Furthermore, the PEIS (BOEM 2014a) proposed that no seismic surveys would be authorized in right whale critical habitat during 15 November – 15 April, nor in the mid-Atlantic and southeast SMAs during 1 November – 30 April, or in any DMAs. Under Alternative B, which was selected by BOEM in their Record of Decision (BOEM 2014b), the area within 20 n.mi. of the coast from Delaware Bay to the southern boundary of the South Atlantic Planning Area is also restricted to seismic surveys between 1 November and 30 April (for Delaware, Maryland, Virginia, and North Carolina), and between 15 November and 15 April (for offshore Florida). None of the proposed seismic survey lines enter critical habitat or SMAs.

Humpback Whale (*Megaptera novaeangliae*)

The humpback whale is found in all ocean basins (Clapham 2009). As with the right whale, populations were historically depleted by commercial whaling. Though it is a protected species today, human-caused mortality and injury are thought to be slowing the recovery of humpback populations (Waring et al. 2014). A recovery plan has been in place for humpback whales since 1991 (NMFS 1991).

The humpback whale is highly migratory, traveling between mid- to high-latitude waters where it feeds during spring–fall, and lower latitude wintering grounds over shallow banks where it calves and generally does not feed in winter (Winn and Reichley 1985). Although considered to be mainly a coastal species, humpback whales often traverse deep pelagic areas while migrating (Baker et al. 1998; Calambokidis et al. 2001; Garrigue et al. 2002). A small proportion of the Atlantic humpback whale population remains in high latitudes in the eastern North Atlantic during winter (e.g., Christensen et al. 1992).

Humpback whale summer feeding grounds in the North Atlantic range from the northeast coast of the U.S. to the Barents Sea (Katona and Beard 1990; Smith et al. 1999). In the western North Atlantic, the Gulf of Maine humpback stock is recognized as a distinct feeding stock on the basis of strong site fidelity by individual whales to the region and more recent genetic analysis (Palsbøll et al. 2001; Vigness-Raposa et al. 2010; Waring et al. 2014).

In the winter, most humpback whales migrate to nearshore areas and banks in the Dominican Republic, Puerto Rico, and the Virgin Islands to breed and calve (Katona and Beard 1990). However, a significant number of humpback whales remain in mid- and high-latitude regions (Clapham et al. 1993; Swingle et al. 1993). Swingle et al. (1993) reported an increased number of sightings in the vicinity of Chesapeake and Delaware bays in 1992. Humpback whale strandings (mainly of sexually immature animals) were also commonly reported in the U.S. mid-Atlantic and southeastern states, particularly along the Virginia and North Carolina coasts (Wiley et al. 1995). Wiley et al. (1995) concluded that these areas could represent increasingly important habitat for juvenile humpback whales. Unpublished data sources have also reported a number of winter humpback whale sightings in coastal waters of the southeastern U.S. (Waring et al. 2014). Photo-identification studies suggest that the humpbacks that winter off the mid-Atlantic states (New Jersey to North Carolina) are mostly from the Gulf of Maine and Newfoundland feeding stocks, and that the area is a supplemental winter feeding ground (Barco et al. 2002).

Within the proposed survey area, humpbacks have been sighted during all seasons in shelf as well as offshore waters, but most sightings have been reported for shelf waters off the mid-Atlantic especially during the winter; there are very few sightings (or strandings) during summer and fall (DoN 2008a,b,c). Humpback whale concentrations are not expected in the offshore survey area during any season (DoN 2008a,b,c). Humpback whales were recently sighted between ~38–45°N and in waters ~100–2000 m deep during June–August line transects surveys completed by air and ship (Palka 2012). A synthesis of historic records resulted in numerous occurrences (mainly whaling records) of humpback whales in the Straits of Florida throughout the year, but primarily during winter (Schmidly 1981). For summer and fall, DoN (2007a,b) did not report any sightings of humpback whales off Florida, only a few stranding records for the east coast of Florida and the Florida Keys.

Common Minke Whale *(Balaenoptera acutorostrata)*

The minke whale has a cosmopolitan distribution that spans ice-free latitudes (Stewart and Leatherwood 1985). Four populations of the minke whale are recognized in the North Atlantic, including the Canadian East Coast stock that ranges from the eastern U.S. coast to Davis Strait (Donovan 1991; Waring et al. 2014). Minke whales are common off the U.S. east coast over continental shelf waters, especially off New England during spring and summer (CETAP 1982). Seasonal movements in the Northwest Atlantic are apparent, with animals moving south and offshore from New England waters during the winter (DoN 2005; Waring et al. 2014). Minke whales are most abundant and widespread during spring and summer months; the number of minke whales appears to diminish in the fall to the point of being almost absent during winter months. Winter records of minke whales suggest a southerly migration far offshore (past Bermuda) to the West Indies (Mitchell 1991).

There have been very few occurrences of minke whales along the coast from Delaware to Florida during July–December. DoN (2007a,b, 2008 a,b,c) reported a single stranding off Myrtle Beach, South Carolina, in summer; single sightings in summer ~50 km and ~125 km off the coasts of North Carolina and Maryland, respectively, and two sightings 50–75 km off Fort Pierce, Florida in fall. Schmidly (1981) reported a single sighting off South Carolina in August and five minke whale strandings during winter off the Florida Keys. Minkes were sighted during 2004 summer aerial surveys of the mid-Atlantic (Palka 2006), and between ~39–45°N in shallow water out to ~2000 m deep during June–August line transects surveys completed by air and ship (Palka 2012).

Bryde's Whale (*Balaenoptera edeni*)

Bryde's whale occurs in all tropical and temperate waters in the Pacific, Atlantic, and Indian oceans, between 40°N and 40°S (Kato and Perrin 2009). It remains in warm (>16.3°C) waters year-round, but seasonal movements towards the equator in winter and higher latitudes in summer have been reported (Kato and Perrin 2009). It is frequently observed in biologically productive areas such as continental shelf breaks (Davis et al. 2002) and in regions subjected to coastal upwelling (Gallardo et al. 1983; Siciliano et al. 2004).

Bryde's whale is the only baleen whale to occur in the Gulf of Mexico on a regular basis throughout the year (Würsig et al. 2000). In the northern Gulf of Mexico, Bryde's whales are typically sighted in relatively shallow water ~100 m deep (Davis et al. 1998, 2002). However, Mullin and Fulling (2004) reported four sightings for the northeast slope waters, where depths were 200–2000 m. The Gulf of Mexico population of Bryde's whales is considered a separate stock, but currently this stock cannot be differentiated from the Atlantic Ocean stock (Waring et al. 2013).

There have been very few reports of Bryde's whales within or near the proposed survey area. A few stranding records exist for the coast from Georgia to just south of Wilmington, North Carolina (DoN 2008b), but there are no records between Wilmington and Delaware (DoN 2008a,c). There are no records of Bryde's whales off the Florida Keys (DoN 2007b), and only a single summer stranding at Fort Pierce, Florida (DoN 2007a). Based on a synthesis of historic records, Schmidly (1981) reported six Bryde's whale strandings during the months of November and January–May along the coast from approximately Savannah, Georgia, to Vero Beach, Florida. Given these limited records, Bryde's whales are not likely to be encountered during the proposed survey.

Sei Whale (*Balaenoptera borealis*)

The sei whale has a cosmopolitan distribution, with a preference for temperate oceanic waters (Gambell 1985a). It is an oceanic species and is uncommon in shelf waters (Horwood 2009). Gregr and Trites (2001) modeled sei whale occurrence in the eastern North Pacific, and found a preference for deep water and an association with continental shelf breaks and seamounts. Two stocks of sei whales are recognized in the western North Atlantic: the Labrador Sea Stock and the Nova Scotia Stock; the latter has a distribution that includes continental shelf waters from the northeastern U.S. to areas south of Newfoundland (Waring et al. 2014).

The sei whale is migratory and moves to higher latitude waters in summer, where most feeding takes place (Jonsgård 1966; Jonsgård and Darling 1977). The Nova Scotia stock's range includes the Gulf of Maine and Georges Bank during spring and summer (Waring et al. 2014). Mitchell and Chapman (1977) suggested that this stock moves from spring feeding grounds on or near Georges Bank to the Scotian Shelf in June and July, eastward to Newfoundland and the Grand Banks in late summer, back to the Scotian Shelf in fall, and offshore and south in winter. During summer and fall, most sei whale sightings occur in feeding grounds in the Bay of Fundy and on the Scotian Shelf; sightings south of Cape Cod are rare (DoN 2005). In the winter, some whales have been seen from Cape Cod south to Florida (Mitchell and Chapman 1977) and from South Carolina south into the Gulf of Mexico and the Caribbean (Rice 1998).

There have been very few reports of sei whales within or near the proposed survey area. There are no records of sei whales in Florida or Georgia (DoN 2007 a,b) or from South Carolina to Delaware (DoN 2008 b,c). Two sightings have been reported ~75 km offshore from Maryland in the summer (DoN 2008a). A synthesis of historic records yielded only two sei whale strandings: one whale stranded in North Carolina in April, and a second whale stranded in South Carolina in December (Schmidly 1981). Finally, a maximum of eight sei whale sightings were made between ~40–43°N in shallow waters out to ~2000 m deep during June–August line transects surveys completed by air and ship (Palka 2012). Given these limited records, sei whales are not likely to be encountered during the proposed survey.

Fin Whale (*Balaenoptera physalus*)

The fin whale is widely distributed in all the world's oceans (Gambell 1985b), but is most abundant in temperate and cold waters (Aguilar 2009). Fin whales most commonly occur offshore, but can also be found in coastal areas (Gregr and Trites 2001; Aguilar 2009). The fin whale migrates seasonally between temperate waters, where it mates and calves in winter, and polar waters, where it feeds in summer (Mackintosh 1965 *in* Gambell 1985b). In the North Atlantic, they are known to use the shelf edge as a migration route between summer feeding areas in high latitudes and southern wintering grounds (Evans 1987). Sergeant (1977) suggested that fin whales tend to follow steep slope contours, either because they detect them readily, or because the contours are areas of high biological productivity.

North Atlantic fin whales are found in the summer from Baffin Bay, Spitsbergen, and the Barents Sea south to North Carolina and the coast of Portugal (Rice 1998). They are most commonly encountered in waters north of Cape Hatteras (Waring et al. 2014). They accounted for 46% of all large whales sighted over the continental shelf during aerial surveys from Cape Hatteras to Nova Scotia (CETAP 1982). During fall, almost all fin whales either move out of U.S. waters to feeding grounds in the Bay of Fundy and on the Scotian Shelf, remain at Stellwagen Bank and Murray Basin (DoN 2005), or begin a southward migration (Clark 1995). Apparently not all individuals migrate, because in winter they have been sighted from Newfoundland to the Gulf of Mexico and the Caribbean Sea, and from the Faroes and Norway south to the Canary Islands (Rice 1998).

There have been numerous summer and fall fin whale occurrences within and near the proposed survey area. There was one fall stranding at the Florida/Georgia border, two fall strandings in South Carolina (DoN 2008b), and 7–10 sightings near the shelf break off North Carolina and Virginia during summer and fall (DoN 2008a). Off the coasts of Maryland and Delaware, there were ~45 sightings out to, and beyond, the shelf break in the summer; and ~6 sightings and one stranding spread over an area extending from the coast to beyond the shelf break in fall (DoN 2008a). There were no summer or fall occurrences of fin whales in either the Florida Keys or along the southeast Florida coast (DoN 2007a,b). Fin whales have also been sighted during numerous other summer and fall surveys of the mid-Atlantice shelf break area from North Carolina to Delaware (Palka 2006, 2012; Garrison et al. 2010; Wicker et al. 2011; Wicker and Mullin 2012). Finally, a synthesis of historic records yielded 12 occurences (11 strandings and 1 sighting) of fin whales: seven occurrences off North Carolina, and four occurrences off Florida (Cape Canaveral, Florida Bay, Florida Keys); the majority of occurrence were during January–May (Schmidly 1981).

Blue Whale (*Balaenoptera musculus*)

The blue whale is widely distributed throughout the world's oceans, occurring in pelagic, continental shelf, and inshore waters (Leatherwood and Reeves 1983). Blue whale distribution is likely dictated by food availability for much of the year (Sears and Perrin 2009), and blue whales have been commonly found in areas with high primary productivity (Branch et al. 2007). In the western North Atlantic, the distribution of the blue whale extends as far north as Davis Strait and Baffin Bay (Sears and Perrin 2009), but the southern limit of its range is unknown (Waring et al. 2011). The U.S. Navy's Sound Surveillance System (SOSUS) program has acoustically tracked blue whales throughout most of the North Atlantic, including deep waters east of the U.S. Atlantic EEZ and subtropical waters north of the West Indies (Clark 1995).

There are very few occurrences of blue whales in or near the proposed survey area. Wenzel et al. (1988) reported three blue whales in the Gulf of Maine in summer and fall. True (1904 *in* NMFS 1998) reported a single stranding off Maryland in October. A single blue whale was spotted ~250 km offshore from Virginia during 6 December–5 April (DoN 2008a). Wicker and Mullin (2012) sighted one blue whale ~1000 m offshore from Delaware Bay during November 2011. There were no occurences of blue whales in the historic records compiled by Schmidly (1981). Both Wenzel et al. (1988) and Waring et al. (2011) have suggested that the blue whale is at best an occasional visitor in U.S. Atlantic EEZ waters.

Odontocetes

Sperm Whale *(Physeter macrocephalus)*

Sperm whales are widely distributed and occur from the edge of the polar pack ice to the equator in both hemispheres (Whitehead 2009). In general, they are distributed over large temperate and tropical areas

that have high secondary productivity and steep underwater topography, such as volcanic islands (Jacquet and Whitehead 1996); their distribution and relative abundance can vary in response to prey availability, most notably squid (Jacquet and Gendron 2002). In the northwest Atlantic, sperm whales generally occur in deep water along the continental shelf break from Virginia to Georges Bank, and along the northern edge of the Gulf Stream (Waring et al. 2001). Shelf edge, oceanic waters, seamounts, and canyon shelf edges are also predicted habitats of sperm whales in the northwest Atlantic (Waring et al. 2001).

There are numerous records of sperm whales throughout the proposed survey area, including during the summer and fall (DoN 2007a,b, 2008a,b,c). There were hundreds of sightings offshore from Cape Hatteras to Delaware in summer, <20 sightings offshore in fall, and six strandings along the coast of North Carolina in summer and fall, combined (DoN 2008a). Sperm whales have also been regularly sighted during summer and fall line transect surveys in the mid-Atlantic shelf break area (Martinez and Garrison 2005, 2006; Garrison et al. 2010; Wicker et. al 2011; Wicker and Mullin 2012; Palka 2012). Off the east coast of Florida, there are reports of single offshore sightings northeast of Fort Pierce during the fall and northeast of Cape Canaveral during the spring (DoN 2007a). Strandings occur along the coast from the Florida Keys to North Carolina throughout the year (DoN 2007a, 2008b). Sperm whales are regularly sighted in the Gulf of Mexico year-round (DoN 2007a,b). Most sighting records for the western Straits of Florida (southwest of the Florida Keys) have been reported for spring, but one summer sighting has also been reported (DoN 2007b). Schmidly's (1981) synthesis of historic records yielded numerous occurrences in mainly offshore areas from the Florida Keys to Cape Hatteras throughout the year.

Pygmy and Dwarf Sperm Whales (*Kogia* spp.)

Dwarf sperm whales (*Kogia sima*) and pygmy sperm whales (*K. breviceps*) are distributed widely throughout tropical and temperate seas, but their precise distributions are unknown because much of what we know of the species comes from strandings (McAlpine 2009). They are difficult to sight at sea, because of their dive behavior and perhaps because of their avoidance reactions to ships and behavior changes in relation to survey aircraft (Würsig et al. 1998). The two species are often difficult to distinguish from one another when sighted (McAlpine 2009).

Both *Kogia* species are sighted primarily along the continental shelf edge and slope and over deeper waters off the shelf (Hansen et al. 1994; Davis et al. 1998; Jefferson et al. 2008). Several studies have suggested that pygmy sperm whales live mostly beyond the continental shelf edge, whereas dwarf sperm whales tend to occur closer to shore, often over the continental shelf (Rice 1998; Wang et al. 2002; MacLeod et al. 2004). Barros et al. (1998), on the other hand, suggested that dwarf sperm whales could be more pelagic and dive deeper than pygmy sperm whales. It has also been suggested that the pygmy sperm whale is more temperate, and the dwarf sperm whale more tropical, based at least partially on live sightings at sea from a large database from the eastern tropical Pacific (Wade and Gerrodette 1993). This idea is also supported by the distribution of strandings in South American waters (Muñioz-Hincapié et al. 1998).

A synthesis of historic records yielded year-round occurences (predominantly strandings) of pygmy and dwarf sperm whales: 121 occurrences of pygmy sperm whales in coastal and offshore waters from North Carolina to south Florida, including the Florida Keys; and 30 occurrences of dwarf sperm whales along the coast from North Carolina to Cape Canaveral, Florida (Schmidly 1981). Credle (1988) summarized historical stranding records from 1883 to 1988, and found that pygmy sperm whales accounted for ~83% of all *Kogia* spp. strandings in the southeastern U.S.

DoN (2007a, 2008a,b,c) reported numerous stranding records throughout the year along the coast of Florida, and from South Carolina to Delaware, with the majority of strandings along the Florida coast. Strandings for the Florida Keys have only been reported during winter–spring (DoN 2007b). There have been several fall sightings within the proposed survey area including: a *Kogia* spp. in the western Straits of Florida southwest of the Florida Keys (DoN 2007b); a single pygmy sperm whale ~75 km offshore just south of Cape Canaveral (DoN 2007a); a single dwarf sperm whale ~75 km offshore just north of Cape Canaveral (DoN 2007a); and 15 sightings of *Kogia* spp. at or beyond the shelf break from North Carolina to Delaware (DoN 2008a). DoN (2007a) also reported a summer *Kogia* spp. sighting ~150 km offshore from Cape Canaveral.

Palka (2012) sighted both pygmy and dwarf sperm whales during during June–August line transect surveys completed by air and ship; both species were sighted in water depths of ~2000–4000 m. Pygmy sperm whales were sighted slightly farther north (~37–41°N) than dwarf sperm whales (~39–41°N). *Kogia* spp. were also sighted during summer vessel-based surveys from Cape Canaveral to Delaware Bay; sightings occurred in deep waters (>200 m) between ~33–38°N (Martinez and Garrison 2006; Wicker et al. 2011; Wicker and Mullin 2012). Finally, Garrison et al. (2010) sighted *Kogia* spp. on the mid-Atlantic shelf break and slope during summer line transect surveys.

Cuvier's Beaked Whale (*Ziphius cavirostris*)

Cuvier's beaked whale is probably the most widespread and common of the beaked whales, although it is not found in high-latitude polar waters (Heyning 1989). It is rarely observed at sea and is mostly known from strandings; it strands more commonly than any other beaked whale (Heyning 1989). Cuvier's beaked whale is found in deep water, but it appears to prefer steep continental slope waters (Reeves et al. 2002; Jefferson et al. 2008) and is most common in water depths >1000 m (Heyning 1989). In the western North Atlantic, Cuvier's beaked whale occurs from Massachusetts to Florida, the West Indies, and the Gulf of Mexico (Würsig et al. 2000). Most sightings off the eastern U.S. coast occur in late spring or summer. Strandings have been reported as far north as Nova Scotia (Waring et al. 2014).

Cuvier's beaked whales have been regularly sighted during summer and fall line transect surveys in the mid-Atlantic shelf break area (Martinez and Garrison 2005, 2006; Wicker et. al 2011; Wicker and Mullin 2012; Palka 2012). DoN (2008a,b) reported eight sightings offshore from Georgia and North Carolina in the fall, most of which occurred near the shelf break. Several summer and fall strandings have also been reported along the coast from south Florida to North Carolina (DoN 2007a, 2008a,b). Based on a synthesis of historic records, Schmidly (1981) reported 29 occurences (all strandings) of Cuvier's beaked whales; strandings were recorded year-round and occurred along the coast from Cape Hatteras to south Florida, with a single stranding in the Florida Keys

Northern Bottlenose Whale (*Hyperoodon ampullatus*)

Northern bottlenose whales are found in the North Atlantic, mainly in cold temperate and subarctic waters (Reeves et al. 2002). In the western Atlantic, their range extends from the subarctic south to New England, although strandings have occurred as far south as North Carolina (Jefferson et al. 2008). The two main centers of northern bottlenose whale distribution are "The Gully", south of Nova Scotia, and Davis Strait, off the coast of Labrador (Reeves et al. 1993). The current estimate for the Scotian Shelf population is 143 individuals (O'Brien and Whitehead 2013); the size of the Davis Strait-Baffin Bay-Labrador Sea population is uncertain (Whitehead and Hooker 2012).

Bottlenose whales are most common in deep waters beyond the continental shelf or over submarine canyons, usually over 500–1000 m deep (Jefferson et al. 2008). Northern bottlenose whales tagged off

Nova Scotia were found to dive approximately every 80 min to over 800 m, with a maximum dive depth of 1453 m (Hooker and Baird 1999). Most dives are <10 min, and the longest dives are 1–2 h (Jefferson et al. 2008). Bottlenose whales typically travel in groups of at least 4, and up to 20 (Mead 1989a; Jefferson et al. 2008).

Northern bottlenose whales are unlikely to occur in any of the survey areas. Only two sightings of three individuals (out of a total of 11,156 sightings) were recorded during the CETAP surveys from 1978 to 1982 (CETAP 1982). Both sightings were recorded in the spring along the 2000-m isobath. One and two additional sightings of northern bottlenose whales were recorded during shipboard surveys along the southern edge of Georges Bank during summer months in 1993 and 1996, respectively (NMFS 1993, 1996 *in* Waring et al. 2009).

Mesoplodont Beaked Whales

Mesoplodont beaked whales (*Mesoplodon* spp.) are difficult to distinguish in the field, and confirmed at-sea sightings are rare (Mead 1989b; Jefferson et al. 2008; Waring et al. 2014). Mesoplodonts are distributed primarily in deep waters (>2000 m) and along continental slopes at depths 200–2000 m and are rarely found in continental shelf waters (Pitman 2009). Most mesoplodonts identified to species are known from strandings involving single individuals (Pitman 2009). Most sightings off the U.S. Atlantic coast are from late spring or summer, corresponding with survery effort (Waring et al. 2014); thus, it is not possible to identify spatial or seasonal patterns in their distribution. Because of the scarcity of sightings, most of these beaked whales are thought to be rare.

Four species of *Mesoplodon* have been recorded off the eastern coast of the U.S., based almost entirely from strandings: True's beaked whale, Gervais' beaked whale, Sowerby's beaked whale, and Blainville's beaked whale (Mead 1989b; Macleod and Mitchell 2006). Macleod and Mitchell (2006) identified the continental shelf margins from Cape Hatteras to southern Nova Scotia and east to the start of the abyssal plain as a key area for beaked whales. Within the proposed survey area, there are numerous beaked whale sighting records for the Mid-Atlantic region from winter through summer, but very few records during the fall (DoN 2008a,b,c). There are only a few summer sighting records of unidentified beaked whales off the coast from North Carolina to northern Florida, but none during fall (DoN 2008b). One unidentified beaked whale sighting was also reported during the fall in the western Straits of Florida (DoN2007b).

True's Beaked Whale (Mesoplodon mirus).—In the North Atlantic, True's beaked whale occurs from Nova Scotia and Ireland south to Florida, the Bahamas, and the Canary Islands (Rice 1998). Carwardine (1995) suggested that this species could be associated with the Gulf Stream.

DoN (2007a) reported two True's beaked whale strandings during fall at West Palm Beach and Cape Canaveral. Based on historic records, Schmidly (1981) reported six strandings of True's beaked whales along the coasts of North and South Carolina and Florida; strandings occurred in March, July, and August.

Gervais' Beaked Whale (M. europaeus).—Gervais' beaked whale is mainly oceanic and occurs in tropical and warmer temperate waters of the Atlantic Ocean from Ireland to southeast Brazil (MacLeod et al. 2006; Jefferson et al. 2008). Strandings are thought to be associated with calving, which could take place in shallow water; pregnant females or those with calves have stranded in May, June, and August in the southeastern U.S. and Gulf of Mexico, indicating a spring–summer calving period (Würsig et al. 2000).

Gervais' beaked whales were sighted during summer line transect surveys between ~37–39°N and in waters ~3000–4000+ m deep (Palka 2012). DoN (2008a,b) reported nine summer and thirteen fall strandings between Georgia and North Carolina. There were 20 occurrences of Gervais' beaked whales in the historic records compiled by Schmidly (1981); strandings occurred year-round with the majority of strandings in Florida and North Carolina. There were two strandings in the Florida Keys (Schmidly 1981).

Sowerby's Beaked Whale (M. bidens).—Sowerby's beaked whale occurs in cold temperate waters of the North Atlantic (Mead 1989b) from the Labrador Sea to the Norwegian Sea, and south to New England, the Azores, and Madeira.

DoN (2007a) reported two sightings of Sowerby's beaked whale off North Carolina near the shelf break in fall, and DoN (2008b) reported a single stranding off the Georgia coast in summer (DoN 2008b). A stranding on the west coast of Florida is thought to be a stray (MacLeod et al. 2006). Sowerby's beaked whales were sighted during summer line transect surveys between ~40–41°N and in waters ~2000–4000+ m deep (Palka 2012). There were no occurrences of Sowerby's beaked whale in the historic records compiled by Schmidly (1981).

Blainville's Beaked Whale (M. densirostris).—Blainville's beaked whale is the most widely distributed *Mesoplodon* species (Mead 1989b), although it is generally limited to pelagic tropical and warmer temperate waters (Jefferson et al. 2008). Occasional occurrences in cooler, higher-latitude waters are presumably related to warm-water incursions (Reeves et al. 2002). Detailed studies in the Bahamas indicated that Blainville's beaked whales prefer moderate-depth waters of 200–1000 m (Jefferson et al. 2008). In the western North Atlantic, Blainville's beaked whale is found from Nova Scotia to Florida, the Bahamas, and the Gulf of Mexico (Würsig et al. 2000). Mead (1989b) suggested that the Nova Scotia records represented strays from Gulf Stream waters.

A single Blaineville's beaked whale was sighted during late June/early July at ~33°N in water >200 m deep (Wicker et al. 2011). DoN (2007a) reported two strandings of Blaineville's beaked whales in the summer between West Palm Beach and Cape Canaveral. There were seven occurrences (all strandings) of Blaineville's beaked whales in the historic records compiled by Schmidly (1981); strandings occurred in January, March, June, and October along the coastline from Florida to North Carolina.

Rough-toothed Dolphin (*Steno bredanensis*)

The rough-toothed dolphin is distributed worldwide in tropical, subtropical, and warm temperate waters (Miyazaki and Perrin 1994). It is generally seen in deep, oceanic water, although it can occur in shallow coastal waters in some locations (Jefferson et al. 2008). The rough-toothed dolphin rarely ranges north of 40°N (Jefferson et al. 2008).

Rough-toothed dolphins were sighted during 2011 summer line transects studies in the mid-Atlantic region: several rough-tooted dolphins were seen between ~37–39°N in waters ~2000–4000 m deep (Palka 2012), and a single dolphin was observed at ~34°N in water >200 m deep (Wicker et al. 2011). DoN (2008a) reported one stranding and one sighting off North Carolina in the fall, and two strandings and one sighting off North Carolina in the summer; both sightings occurred ~100 km beyond the shelf break. DoN (2007a) reported seven fall strandings along the south Florida coast, and one summer sighting has been reported for the western Straits of Florida (DoN 2007b). There were four records of rough-toothed dolphins in the historic data compiled by Schmidly (1981); strandings occurred in North Carolina, Georgia, Cape Canaveral, and Key West.

Bottlenose Dolphin (*Tursiops truncatus*)

In the northwest Atlantic, the common bottlenose dolphin occurs from Nova Scotia to Florida, the Gulf of Mexico and the Caribbean, and south to Brazil (Würsig et al. 2000). Densities of bottlenose dolphins tend to be lowest over the shelf, and higher along the coast and near the shelf edge (CETAP 1982). There are regional and seasonal differences in the distribution of the offshore and coastal forms of bottlenose dolphins off the U.S. east coast (Waring et al. 2014). North of Cape Hatteras, and during summer, coastal bottlenose dolphins generally occur in water <25 m deep, whereas the offshore stock occurs along the shelf break (CETAP 1982; Kenney 1990). During winter, and south of Cape Hatteras, the coastal and offshore morphotypes overlap to some extent (Garrison et al. 2003 *in* Waring et al. 2014). The coastal morphotype is separated into several discrete stocks (McLellan et al. 2003; Rosel et al. 2009); however, the offshore stock is more likely to be encountered during the proposed survey.

Although strandings of bottlenose dolphins are a regular occurrence along the U.S. east coast, an unusually high number of dead or dying bottlenose dolphins have been recorded have washed up on the mid-Atlantic coast from New York to Florida since July 2013 (1283 as of 18 May 2014; NOAA 2014b). NOAA declared an unusual mortality event (UME), the tentative cause of which is thought to be cetacean morbillivirus. As of 12 May 2014, 215 of 225 dolphins tested were confirmed positive or suspect positive for morbillivirus. NOAA personnel observed that the dolphins affected live in nearshore waters, whereas dolphins in offshore waters >50 m deep did not appear to be affected (Environment News Service 2013). It is uncertain exactly what populations have been affected (NOAA 2014b). In addition to morbillivirus, the bacteria *Brucella* was confirmed in 20 of 64 dolphins tested (NOAA 2014b).

DoN (2007a,b, 2008a,b) reported hundreds of sightings and strandings along the entire coast from Delaware to south Florida and the Florida Keys; sightings were made throughout the year along the coast and waters out beyond the shelf break. There were also hundreds of occurrences of bottlenose dolphins in the historic records (strandings and sightings) compiled by Schmidly (1981); these occurred year-round and along the entire coast from Cape Hatteras to the Florida Keys, and included occurrences in Florida Bay. Bottlenose dolphins have been regularly sighted during summer and fall line transect surveys in the mid-Atlantic shelf break area; sightings occurred in water depths ranging from <100–4000+ m (Martinez and Garrison 2005, 2006; Garrison et al. 2010; Wicker et. al 2011; Wicker and Mullin 2012; Palka 2006, 2012). Martinez and Garrison (2006) also reported bottlenose dolphins near the Dry Tortugas Islands, Florida, during August.

Pantropical Spotted Dolphin (*Stenella attenuata*)

The pantropical spotted dolphin is distributed worldwide in tropical and some subtropical waters (Perrin 2009a). It generally occurs in deep offshore waters between 40°N and 40°S, although it may occur close to shore where water near the coast is deep (Jefferson et al. 2008). There are two forms of pantropical spotted dolphin, coastal and offshore forms, although the coastal form occurs mainly in the eastern tropical Pacific (Jefferson et al. 2008). In the western North Atlantic, the pantropical spotted dolphin occurs from North Carolina to the West Indies and south to the equator (Würsig et al. 2000).

There have been several summer and fall occurrences of pantropical spotted dolphins within or near the proposed study area, including five strandings off southern Florida; a single stranding off South Carolina in fall; a single sighting near the shelf break off North Carolina in fall; ~10 sightings close to and out beyond the shelf break off the Florida coast, with one sighting made at ~77°W; and two sightings in the western Straits of Florida (DoN 2007a,b, 2008a,b). There were also ~90 sightings of "spotted dolphins" (unidentified) out to and beyond the shelf break off Georgia–North Carolina in the fall (DoN

2008a,b). Few pantropical spotted dolphin sightings have been made during summer cetacean surveys in the mid-Atlantic (Martinez and Garrison 2005; Garrison et al. 2010; Wicker et al. 2011). The sighting made by Wicker et al. (2011) occurred in water >200 m deep. There were no occurences of pantropical spotted dolphins in the historic records compiled by Schmidly (1981).

Atlantic Spotted Dolphin (*Stenella frontalis*)

The Atlantic spotted dolphin is distributed in tropical and warm temperate waters of the western North Atlantic (Leatherwood et al. 1976). There are two forms of Atlantic spotted dolphin, a large, heavily spotted coastal form that is usually found on the shelf, and a smaller and less spotted offshore form (Waring et al. 2014). In the western Atlantic, its distribution extends from southern New England, south to the Gulf of Mexico, the Caribbean Sea, Venezuela, and Brazil (Leatherwood et al. 1976; Perrin et al. 1994a; Rice 1998).

DoN (2007a, 2008a,b) reported hundreds of summer and fall sightings of Atlantic spotted dolphins within and near the proposed survey area from Delaware to southeastern Florida; numerous sightings occurred out to and beyond the shelf break. Fewer records exist for the Florida Keys, with just a few sightings during spring and summer, but numerous sightings during summer and fall to the northwest of the Keys into the Gulf of Mexico (DoN 2007b). Atlantic spotted dolphins have been regularly sighted during summer and fall line transect surveys in the mid-Atlantic shelf break area; sightings occurred in water depths ranging from ~100–4000+ m (Martinez and Garrison 2005, 2006; Garrison et al. 2010; Wicker et. al 2011; Wicker and Mullin 2012; Palka 2012); they have also been sighted near the Dry Tortugas during fall (Wicker et al. 2011; Wicker and Mullin 2012). There were 64 occurrences of Atlantic spotted dolphins (*S. frontalis* and *S. plagiodon*) in the historic records compiled by Schmidly (1981). Strandings and sightings of spotted dolphins were recorded year-round and along the coast from Cape Hatteras to the Florida Keys; sightings were made out to water depths of ~200 m (Schmidly 1981).

Spinner Dolphin (*Stenella longirostris*)

The spinner dolphin is pantropical in distribution, with a range nearly identical to that of the pantropical spotted dolphin, including oceanic tropical and sub-tropical waters between 40ºN and 40ºS (Jefferson et al. 2008). It is generally considered a pelagic species (Perrin 2009b), but is commonly found around oceanic islands (Rice 1998). Spinner dolphins typically inhabit deep waters (Davis et al. 1998), and they usually feed at night on mesopelagic fish, squid, and shrimp that are in waters at least 200–300 m deep (Perrin and Gilpatrick 1994). Spinner dolphins are extremely gregarious, and usually form large schools when in the open sea and small ones in coastal waters (Perrin and Gilpatrick 1994). They often travel in mixed-groups with pantropical spotted dolphins and other species (Perrin 2009b).

DoN (2007a, 2008a,b) reported very few summer and fall occurrences of spinner dolphins in or near the proposed survey area, including one summer stranding at the Florida/Georgia border; one summer stranding between Fort Pierce and West Palm Beach; one fall stranding off North Carolina; two sightings beyond the shelf break in summer (Virgnia and Cape Canaveral); and one sighting ~50 km offshore south of Cape Canaveral in the fall. DoN (2007b) only reported sightings in the Straits of Florida during spring, and two strandings in the Florida Keys during summer. A single spinner dolphin sighting was made in late June/early July at ~35°N in water 200 m deep (Wicker et al. 2011). There were seven spinner dolphin strandings in the historic records compiled by Schmidly (1981); these occurred during October–May, and took place along the coast in North Carolina, South Carolina, and in Florida, as far south as Fort Pierce.

Clymene Dolphin (*Stenella clymene*)

The Clymene dolphin only occurs in tropical and subtropical waters of the Atlantic Ocean (Jefferson et al. 2008). Clymene dolphins inhabit areas where water depths are 700–4500 m or deeper (Fertl et al. 2003). In the western Atlantic, it occurs from New Jersey to Florida, the Caribbean Sea, the Gulf of Mexico, and south to Venezuela and Brazil (Würsig et al. 2000).

DoN (2007a, 2008a,b) reported a number of summer and fall occurrences of Clymene dolphins near or within the proposed survey area: several strandings along southern coast of Florida including the Florida Keys during fall; one stranding in North Carolina in the summer; one sighting off Georgia; five sightings off North Carolina, two sightings off Maryland in the summer; and three sightings of North Carolina in the fall. All sightings off North Carolina and Maryland took place at or beyond the shelf break; the sighting off Georgia took place ~40 km from shore (DoN 2008a,b). Clymene dolphins have also been sighted during recent summer cetacean surveys: there were four sightings between ~35–36°N in waters >2000 m deep (Martinez and Garrision 2006); and a single sighting just north of the Dry Tortugas in waters ~200 m deep (Wicker et al. 2011). There were three Clymene dolphin strandings in the historic records compiled by Schmidly (1981); these occurred along the northeastern coast of Florida above 29°N.

Striped Dolphin (*Stenella coeruleoalba*)

The striped dolphin has a cosmopolitan distribution in tropical to warm temperate waters (Perrin et al. 1994b). Striped dolphins are pelagic and seem to prefer the deep water seaward of the continental shelf (Davis et al. 1998). However, they are also known to occur in coastal waters (Isaksen and Syvertsen 2002). In the western North Atlantic, this species occurs from Nova Scotia to the Gulf of Mexico and south to Brazil (Würsig et al. 2000).

DoN (2007a,b, 2008a,b) reported a number of summer and fall occurrences of striped dolphins within or near the proposed survey area: 15 strandings along the coast from Florida–Delaware in summer; nine strandings along the coast from North Carolina–Virginia in fall; a single sighting ~120 km offshore from Fort Pierce, Forida in summer; one sighting in the western Florida Straits during summer; ~50 sightings offshore from North Carolina–Delaware in summer; and ~10 sightings off Virginia–North Carolina in fall. Sightings occurred at or beyond the shelf break (DoN 2008a). Striped dolphins have also been regularly sighted during summer and fall line transect surveys in the mid-Atlantic shelf break area; sightings occurred in water depths ranging from ~100–4000+ m (Martinez and Garrison 2005, 2006; Garrison et al. 2010; Wicker et. al 2011; Wicker and Mullin 2012; Palka 2012). There were 17 occurrences of striped dolphins in the historic records compiled by Schmidly (1981); strandings occurred during October–May along the coast from North Carolina to Miami.

Fraser's Dolphin (*Lagenodelphis hosei*)

Fraser's dolphin is a pantropical species distributed between 30ºN and 30ºS (Dolar 2009). It only rarely occurs in temperate regions, and then only in relation to temporary oceanographic anomalies such as El Niño events (Perrin et al. 1994c). In the western Atlantic, it ranges from the Gulf of Mexico to Uruguay (Rice 1998). Fraser's dolphins typically occur in water at least 1000 m deep. They feed on mesopelagic fish, shrimp, and squid, diving to depths of at least 250–500 m (Dolar 2009). They have been observed in mixed groups with other dolphin species (Rudolph and Smeenk 2009).

There are few records of Fraser's dolphin near or within the proposed survey area; summer or fall occurrences include a sighting off North Carolina during the fall and two fall strandings in the Florida

Keys (DoN 2007b, 2008a). There were no occurences of Fraser's dolphin in the historic records compiled by Schmidly (1981).

Short-beaked Common Dolphin (*Delphinus delphis*)

There are two species of common dolphin, the more coastal long-beaked dolphin (*Delphinus capensis*) and the more offshore short-beaked dolphin (*D. delphis*). The short-beaked common dolphin is found in tropical and warm temperate oceans around the world (Perrin 2009c) and is more widely distributed compared to the long-beaked common dolphin (Heyning and Perrin 1994). Common dolphins found in the survey area likely would be the short-beaked species. In the Atlantic Ocean, common dolphins usually occur along the shelf break at depths 200–300 m, or over prominent underwater topography such as sea mounts (Evans 1994).

DoN (2007a, 2008a,b) reported a number of summer and fall occurrences of common dolphins near or within the proposed survey area including ~35 sightings in each of summer and fall along the coast from North Carolina to Delaware (most sightings were at or beyond the shelf break, and most summer sightings occurred off southern Maryland); three strandings in the summer off the coast of North Carolina; five strandings in the fall off the coasts of Georgia, South and North Carolina; and two sightings off Florida in the fall (one ~20 km offshore between Miami and West Palm Beach, and the other occurred far offshore from Cape Canaveral at ~77.5°W). Short-beaked common dolphins have also been regularly sighted during summer and fall line transect surveys in the mid-Atlantic shelf break area; sightings occurred in water depths ranging from ~100–4000 m (Martinez and Garrison 2005, 2006; Garrison et al. 2010; Wicker et. al 2011; Wicker and Mullin 2012; Palka 2012). There were 21 occurrences (sightings and strandings) of common dolphins in the historic records compiled by Schmidly (1981). The majority of occurrences took place during January–June, and along the coasts of North and South Carolina, and Florida, as far south as Miami. There was a single sighting of a common dolphin in waters ~200 m deep off the northern coast of Florida (Schmidly 1981).

Atlantic White-sided Dolphin (*Lagenorhynchus acutus*)

The Atlantic white-sided dolphin occurs in cold temperate to subpolar waters of the North Atlantic in deep continental shelf and slope waters (Jefferson et al. 2008). It is often found concentrated in areas with high seafloor relief (Reeves et al. 2002). In the western North Atlantic, the Atlantic white-sided dolphin ranges from Labrador and southern Greenland to ~38ºN (Jefferson et al. 2008).

DoN (2008a) reported few summer and fall occurrences of white-sided dolphins within or near the proposed survey area, including four sightings in each of summer and fall off the coasts of Virginia and Maryland; the majority of the sightings were close to or beyond the shelf break, although one sighting was made along the coast of Virginia. There was also a single summer stranding on the Virigina coast (DoN 2008a). White-sided dolphins were sighted during a summer cetacean survey in waters >42°N and generally <100 m deep (Palka 2012). There were no occurrences of Atlantic white-sided dolphins in the historic records compiled by Schmidly (1981).

Risso's Dolphin (*Grampus griseus*)

Risso's dolphin is distributed worldwide in temperate and tropical oceans (Baird 2009a). It has an apparent preference for steep sections of the continental shelf 400–1000 m deep (Baird 2009a), and is known to frequent seamounts and escarpments (Kruse et al. 1999). It also occurs in oceanic areas, and its range includes some semi-enclosed seas (Taylor et al. 2012).

DoN (2007a, 2008a,b) reported a number of summer and fall occurrences of Risso's dolphins within or near the proposed survey area, including 20 strandings and ~200 sightings along the coast from Florida to Delaware; nearly all sightings were made beyond the shelf break. There were many more summer sightings than fall sightings, and overall, the majority of sightings occurred off Maryland and Delaware. Risso's dolphins have also been regularly sighted during summer and fall line transect surveys in the mid-Atlantic shelf break area; sightings occurred in water depths ranging from 100–4000 m (Martinez and Garrison 2005, 2006; Garrison et al. 2010; Wicker et. al 2011; Wicker and Mullin 2012; Palka 2012). Additionally, Risso's dolphins were sighted near the Dry Tortugas in water 200–1000 m deep during the summer and fall (Martinez and Garrison 2005; Wicker et al. 2011; Wicker and Mullin 2012). There were 10 Risso's dolphin strandings in the historic records compiled by Schmidly (1981); these occurred primarily during January–May, and along the Florida coast, including a single stranding in the Keys. There were also single strandings in each of North and South Carolina (Schmidly 1981).

Melon-headed Whale (*Peponocephala electra*)

The melon-headed whale is an oceanic species found worldwide in tropical and subtropical waters. It occurs most often in deep offshore waters and occasionally in nearshore areas where deep oceanic waters occur near the coast (Perryman 2009). Most sightings are from the continental shelf seaward, and around oceanic islands (Taylor et al. 2008). Occasional occurrences in temperate waters are extralimital, likely associated with warm currents (Perryman et al. 1994; Reeves et al. 2002; Jefferson et al. 2008). Melon-headed whales have been reported to form mixed groups with Fraser's dolphins, spinner dolphins, and spotted dolphins (Würsig et al. 2000).

DoN (2007a,b, 2008a,b) did not report any summer occurrences of melon-headed whales within or near the proposed survey area, but one whale was sighted ~220 km offshore from Cape Hatteras during the fall (DoN 2008a). There were no occurrences of melon-headed whales in the historic records compiled by Schmidly (1981).

Pygmy Killer Whale (*Feresa attenuata*)

The pygmy killer whale has a worldwide distribution in tropical and subtropical waters (Donahue and Perryman 2009). It is usually seen close to the coast in warm waters, but it is also found in deep waters (Wade and Gerrodette 1993). Very little is known about the natural history of pygmy killer whales.

DoN (2007a,b, 2008a,b) reported 10 pygmy killer whale stranding records near or within the proposed survey area: four summer and one fall stranding in the Florida Keys; three summer and fall strandings along the coast of Florida; and one summer stranding each on the coast of Georgia and North Carolina. There were four pygmy killer whale strandings in the historic records compiled by Schmidly (1981); all strandings occurred along the Florida coast between ~26.5– 27.5°N and took place during the months of March, May, and June.

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 not abundant anywhere (Carwardine 1995). False killer whales generally inhabit deep, offshore waters, but sometimes are found over the continental shelf and occasionally move into very shallow water (Jefferson et al. 2008; Baird 2009b). False killer whales are gregarious and form strong social bonds, as is evident from their propensity to strand en

masse (Baird 2009b). In the western Atlantic, false killer whales occur from Maryland to Argentina (Rice 1998).

DoN (2007a,b, 2008a,b) reported a number of summer and fall occurrences of false killer whales within or near the proposed survey area, including fall strandings in southern and northern Florida (2), Georgia (1), and North Carolina (1); and summer strandings in the Dry Tortugas and Florida Keys (one each). There were also two sightings in summer off North Carolina; one sighting was inshore, and one sighting was offshore of the shelf break (DoN 2008a). False killer whales were sighted during two recent summer cetacean surveys in the mid-Atlantic; there was a single sighting at ~28°N in water >200 m deep (Wicker et al. 2011), and two sightings at ~34–35°N in water 1000–2000+ m deep (Martinez and Garrison 2006). There were 15 occurrences (sightings and strandings) of false killer whales in the historic records compiled by Schmidly (1981) from North Carolina to southern Florida, including the Florida Keys and Dry Tortugas; occurrences were reported year-round.

Killer Whale (*Orcinus orca*)

The killer whale is cosmopolitan and widely distributed; it has been observed in all oceans of the world (Ford 2009). It is very common in temperate waters, and also frequents tropical waters (Heyning and Dahlheim 1988). High densities of the species occur in high latitudes, especially in areas where prey is abundant. Killer whale movements generally appear to follow the distribution of their diverse prey, which includes marine mammals, fish, squid, and turtles. The greatest abundance is thought to occur within 800 km of major continents (Mitchell 1975).

Killer whales are large and conspicuous, often traveling in close-knit matrilineal groups of a few to tens of individuals (Dahlheim and Heyning 1999). In the western North Atlantic, killer whales occur from the polar ice pack to Florida and the Gulf of Mexico (Würsig et al. 2000). Killer whales appear to prefer coastal areas, but are also known to occur in deep water (Dahlheim and Heyning 1999).

DoN (2007a, 2008a) reported one sighting and two strandings of killer whales within or near the proposed survey area; all occurrences took place in the fall. Killer whales stranded off North Carolina and ~150 km offshore from Fort Pierce, Florida. One sighting was reported ~100 km offshore from Fort Pierce. Palka (2012) sighted a single killer whale at ~41°N and in water >4000 m deep during summer 2011. There were 13 occurrences (sightings and strandings) of killer whales in the historic records compiled by Schmidly (1981). These occurred off North and South Carolina, in the Florida Keys, and in the Gulf Stream roughly between Miami Beach and the Bahamas.

Pilot Whales (*Globicephala* spp.)

There are two species of pilot whale, both of which could occur in the survey area. The long-finned pilot whale (*G. melas*) is distributed antitropically, whereas the short-finned pilot whale (*G. macrorhynchus*) is found in tropical, subtropical, and warm temperate waters (Olson 2009). In the northwest Atlantic, pilot whales often occupy areas of high relief or submerged banks and associated with the Gulf Stream edge or thermal fronts along the continental shelf edge (Waring et al. 1992). The ranges of the two species overlap in the shelf/shelf-edge and slope waters of the northeastern U.S. between New Jersey and Cape Hatteras, with long-finned pilot whales occurring to the north (Bernard and Reilly 1999). Pilot whales can be found in both nearshore and pelagic environments. There do not appear to be fixed migrations, but general north-south or inshore-offshore movements occur in relation to prey distribution or incursions of warm water (Olson 2009).

Many pilot whale sightings have not been identified to species. Unidentified pilot whales were regularly sighted during summer and fall line transect surveys in the mid-Atlantic shelf break area; sightings occurred in water depths ranging from ~100–4000 m (Martinez and Garrison 2005, 2006; Garrison et al. 2010; Wicker et. al 2011; Wicker and Mullin 2012; Palka 2012). DoN (2007a,b, 2008a,b) also reported numerous summer and fall occurrences of pilot whales within and near the proposed survey area, including seven pilot whale sightings offshore from North Carolina to northern Florida in summer, one sighting in the western Straitss of Florida during summer, and two sightings off Georgia in the fall. Additionally, hundreds of sightings were reported along the coast from North Carolina–Delaware, and more sightings were made during the summer than fall; all sightings were made in waters beyond the shelf break (DoN 2008a). There was also a total of 25 strandings along the coast from Florida–Virginia during summer and fall combined (DoN 2007a, 2008a,b).

Short-finned Pilot Whale.—The short-finned pilot whale occurs in deep water at the edge of the continental shelf and over deep submarine canyons (Carwardine 1995). It is probably circumglobal in distribution in tropical and warm temperate waters, generally south of 50ºN and north of 40ºS (Jefferson et al. 2008). In the western Atlantic, it occurs from New Jersey to Brazil (Rice 1998).

Palka (2012) sighted short-finned pilot whales at 37–39°N and in water 2000–4000 m deep during summer 2011. DoN (2007a) reported 26 records of short-finned pilot whale strandings along the coast of Florida in the fall. There were 81 occurrences of short-finned pilot whales in the historic records compiled by Schmidly (1981); the majority of occurrences were strandings and occurred year-round, along the coast from Cape Hatteras to the Florida Keys, including Florida Bay. There were six sightings offshore Florida in waters much deeper than 200 m (Schmidly 1981).

Long-finned Pilot Whale.—The North Atlantic subspecies of the long-finned pilot whale ranges in the western Atlantic from Greenland south to North Carolina (Rice 1998). It occurs in water temperatures 0–25ºC, and can be found in inshore or offshore waters (Reyes 1991). The long-finned pilot whale is found in waters 300–1800 m deep, reflecting its preference for the edge of the continental shelf and areas of high relief. The distribution of long-finned pilot whales during winter and early spring months is mainly concentrated off the northeast U.S. coast along the continental shelf edge, and shifts to Georges Bank, the Gulf of Maine, and more northern waters from late spring until late fall (Waring et al. 2014).

Palka (2012) sighted long-finned pilot whales at ~40°N and in water 100–2000 m deep during summer 2011. There were six long-finned pilot whale strandings in the historic records compiled by Schmidly (1981); these occurred along the coast from Georgia to North Carolina, and took place in the months of February, March, July and November.

Harbor Porpoise (*Phocoena phocoena*)

The harbor porpoise inhabits cool temperate to subarctic waters of the Northern Hemisphere (Jefferon et al. 2008). There are likely four populations in the western North Atlantic: Gulf of Maine/Bay of Fundy, Gulf of St. Lawrence, Newfoundland, and Greenland (Gaskin 1984, 1992). Individuals found off the eastern U.S. coast likely would be almost exclusively from the Gulf of Maine/Bay of Fundy stock.

Harbor porpoises inhabit shallow coastal waters of the continental shelf but, occasionally travel over deeper, offshore waters (Jefferson et al. 2008). They are usually seen in small groups of one to three, often including at least one calf; occasionally they form much larger groups (Bjørge and Tolley 2009). During summer, harbor porpoises from the Gulf of Maine/Bay of Fundy stock are concentrated along the coast of Maine and New Brunswick, up to the southwest edge of Nova Scotia, generally in

waters <150 m deep (Waring et al. 2014). During winter, they disperse into the Gulf of Maine and along the eastern U.S. coast as far south as North Carolina.

DoN (2008a) reported a single sighting (~100 km offshore from Maryland in fall) and a single stranding (Maryland in the fall) of harbor porpoise within or near the proposed survey area. Harbor porpoises were also sighted during a summer cetacean survey in waters >42°N and generally <100 m deep (Palka 2012). There were 56 harbor porpoise strandings in the historic records compiled by Schmidly (1981); all took place in North Carolina during February–May.

Pinniped

Harbor Seal (*Phoca vitulina*)

The harbor seal occurs between ~30ºN and 80ºN (Burns 2009). In the western Atlantic, its distribution ranges from the eastern Canadian Arctic and Greenland south to New Jersey, but extralimital records have been documented as far south as Florida (Burns 2009). Harbor seals usually occur in coastal waters, commonly in bays, estuaries, and rivers. Most harbor seals haul out on land daily, although they can spend several days at sea feeding (Jefferson et al. 2008).

Numerous stranding records of harbor seals have been documented near the proposed survey area, including along the coast of Florida (DoN 2007a), South Carolina (DoN 2008b), and from North Carolina to Delaware (DoN 2008a). A total of 161 stranding records of harbor seals were recorded during 2007–2011 between Delaware and Virginia (see NOAA Northeast Stranding Network *in* BOEM 2014a), and Waring et al. (2014) documented 25 stranding mortalities for North Carolina during 2007–2011. Harry et al. (2005) reported 71 harbor seal stranding records for North Carolina and Virginia during 2000–2005; most strandings occurred from November through April.

Although most harbor seal records along the east coast of the U.S. have been reported during winter (DoN 2008a), strandings have been reported off South Carolina at any time of the year (e.g., Caldwell 1961; McFee and Zolman n.d.). DoN (2008a) reported three strandings of harbor seals during the summer–fall period: two fall strandings in North Carolina and one summer stranding in Delaware. There were 25 occurrences of harbor seals in the historic records compiled by Schmidly (1981); the majority of which were strandings. Harbor seals strandings occurred along the coast from North Carolina to northern Florida and occurred predominatly during January–April (Schmidly 1981).

Harp Seal (*Phoca groenlandica*)

Harp seals are found in close association with the pack-ice zone of the North Atlantic; their northern and southern distribution is closely tied to the advance and retreat of the pack ice (Lavigne and Kovacs 1988). In general, harp seals range from Nova Scotia to Greenland, Svalbard, Iceland, Jan Mayen, and northern Norway (Rice 1998), but vagrants have been identified as far south as South Carolina (McFee and Zolman n.d.). Sightings along the U.S. east coast typically occur during January to May (Harris et al. 2002).

A total of 180 stranding records of harp seals were recorded during 2007–2011 between Delaware and Virginia (see NOAA Northeast Stranding Network *in* BOEM 2014a), and Waring et al. (2014) documented three stranding mortalities for North Carolina during 2007–2011. Harry et al. (2005) reported 16 harp seal stranding records for North Carolina and Virginia during 2000–2005. DoN (2008a) reported several strandings of harp seals from Delaware south to North Carolina during winter and spring; one stranding was recorded off Maryland during the fall.

Gray Seal (*Halichoerus grypus*)

Gray seals are found throughout the temperate and subarctic waters of the north Atlantic (King 1983). In the western Atlantic, gray seals occur from Labrador south to Massachusetts (King 1983). However, vagrants have been reported as far south as North Carolina (Waring et al. 2014). Gray seals typically remain over the continental shelf, usually feeding in water <200 m deep (Thompson et al. 1998a). They are capable of dispersing large distances from their breeding or feeding areas (e.g., Thompson et al. 1998a; McConnell et al. 1999; Bjørge et al. 2002).

A total of 205 stranding records of gray seals were recorded during 2007–2011 between Delaware and Virginia (see NOAA Northeast Stranding Network *in* BOEM 2014a), and Waring et al. (2014) reported six stranding mortalities for North Carolina during 2007–2011. Harry et al. (2005) reported eight gray seal stranding records for North Carolina and Virginia during 2000–2005. DoN (2008a) reported several strandings of gray seals from Delaware to North Carolina during winter and spring, but no records were reported for the summer or fall. In addition, Katona et al. (1993 *in* DoN 2008a) reported the birth of two pups in Virginia.

Hooded Seal (*Cystophora cristata*)

Hooded seals inhabit the pack ice zone of the North Atlantic from Baffin Bay, Denmark Straight, northern Greenland Sea, and the Barents Sea, south to the Gulf of St. Lawrence, southern Greenland, Iceland, and Jan Mayen (Rice 1998). They are migratory, often wandering great distances from their pack-ice habitat and have been sighted as far south as Florida, Puerto Rico, and the Virgin Islands in the western Atlantic (Lavigne and Kovacs 1988; Rice 1998; Mignucci-Giannoni and Odell 2001). Occurrences have been reported from Maine to Florida, typically from January to May off New England and during summer and fall off the southeastern U.S. (McAlpine et al. 1999; Harris et al. 2001; Mignucci-Giannoni and Odell 2001).

Five stranding records of hooded seals were recorded during 2007–2011 between Delaware and Virginia (see NOAA Northeast Stranding Network *in* BOEM 2014a), and Waring et al. (2007) documented 12 stranding mortalities from Delaware to North Carolina during 2001–2005. Harry et al. (2005) reported 10 hooded seal stranding records for North Carolina and Virginia during 2000–2005. DoN (2007a) reported several records of live and dead stranded hooded seals for the coast of Florida from late spring through winter. Records have also been documented for Georgia and North Carolina from summer through winter (DoN 2008a,b,c). In addition, DoN (2008a) reported a stranding of a hooded seal along the coast of Delaware during summer, one off New Jersey during fall, and a stranding off Maryland during the fall. There were two strandings of hooded seals for North Carolina and one stranding for Florida in the historic records compiled by Schmidly (1981); strandings were reported for August and November.

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.

ION GeoVentures requests an IHA pursuant to Section 101 (a) (5) (D) of the MMPA for incidental take by harassment during its planned seismic survey off the U.S. east coast in summer–fall 2016.

The operations described in § I have the potential to take marine mammals by harassment. Potential impacts of the seismic survey on marine mammals would be primarily a result of the operation of the airgun array, although sounds would also be generated by a pinger positioning system, vessel echosounders, and general vessel operations. "Takes" by harassment potentially will result when marine mammals near the activities are exposed to the pulsed sounds generated by the seismic source. The effects will depend on the species, the behavior of the animal at the time of reception of the stimulus, and received level of the sound (see § VI/VII). Disturbance reactions are likely by some of the marine mammals in the general vicinity of the tracklines of the source vessel. Given the nature of the planned operations and the mitigation measures that are planned (see § XI), no take by serious injury is anticipated,. No lethal takes are expected.

VI. NUMBERS OF MARINE MAMMALS THAT MAY 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.

All anticipated takes would be "takes by harassment" involving temporary changes in behavior. The mitigation measures to be applied (see § XI below) would minimize the possibility of injurious takes. However, as noted earlier and in Appendix C, there is no specific information demonstrating that injurious "takes" would occur if animals were exposed to sound levels >180 dB re 1μPa SPL rms even in the absence of the planned mitigation measures. In the sections below, we describe methods to estimate the number of potential exposures to various received sound levels and present estimates of the numbers of marine mammals that could be affected during the proposed seismic survey. The estimates are based on consideration of the number of marine mammals that could be disturbed appreciably by ~13,062 km of seismic surveys off the U.S. east coast in summer–fall 2016.

It is assumed that, during simultaneous operations of the seismic source and other sound sources, any marine mammals close enough to be affected by the pinger system or vessel echosounders would already be affected by the seismic sources. However, whether or not the seismic sources are operating simultaneously with the other sources, non-airgun sound sources used during seismic surveys would be expected have a minor impact on marine mammals, as noted by BOEM (2014a). Marine mammals are expected to exhibit no more than short-term and inconsequential responses within their normal set of behaviors, if any, to the low-level pinger system and vessel echosounders, given their characteristics and other considerations (see BOEM 2014a, Appendix D). Such reactions are generally not considered to constitute "taking" (see NMFS 2001; NRC 2005; Southall et al. 2007). Therefore, no additional allowance is included for animals that might be affected by sound sources other than the seismic sources.

Marine Mammal Densities

The marine mammal densities used are consistent with those used by BOEM (2014a, Appendix E) which were derived from DoN (2007c). The large spatial extent of the Mid- and South Atlantic Planning Areas and proposal for year-round operations included in the PEIS required subdivision into regions defined by season and similar bathymetry to allow more appriate acoustic propagation modeling and marine mammal density characterization (BOEM 2014a, Table E-5). Acoustic modeling regions 11–21 are applicable to IONs proposed survey and, with a few minor exceptions described below, the marine mammal densities for those regions (BOEM 2014a; Table E-8) were used in this modeling effort (Table 3).

The densities for minke and humpback whales during the fall season in all regions were increased from 0.0 animals/km^2 shown in BOEM (2014a) to the minimal estimate, as defined by the BOEM PEIS, of 0.00003 animals/km^2 to reflect the potential presence of these species in the survey region during the fall. Similarily, the density of harbor seals was reduced to 0.0 animals/km^2 in all regions except the nearshore region during the summer season (region 14; Table 3). Hooded, gray, and harp seal densities were not included in this modeling effort as they are highly unlikely to occur anywhere in the survey area.

Sound Exposure Modeling: Acoustic Integration Model (AIM)

To estimate the numbers of marine mammals that could receive sound in excess of various thresholds, the Acoustic Integration Model (AIM; Frankel et al. 2002) was applied (see Appendix B for additional information). This is the same method used to estimate potential takes of marine mammals in the PEIS (BOEM 2014a). AIM is a Monte Carlo-based statistical model, strongly based on two earlier models: a whale movement and tracking model developed for the census of the bowhead whale (Ellison et al. 1987), and an underwater acoustic back-scattering model for a moving sound source in an under-ice Arctic environment (Bishop et al. 1987). Because the exact positions of sound sources and animals (sound receivers for the purpose of this analysis) in any given simulation cannot be known, multiple runs of realistic predictions are used to provide statistical validity. The movement and other behavior patterns of sources and receivers are modeled based on measured field data, and these patterns are incorporated into the model. Each source and/or receiver is modeled using the "animat" concept, where each has variables that control its speed and direction in

Table 3. Marine mammal densities (individuals/km^2) used in the AIM model to estimate numbers of marine mammals exposed at different thresholds during the proposed seismic survey off the U.S. east coast in 2016. Original densities (as individuals/n.mi.^{2}) were from BOEM EIS and converted to individuals/km^2 shown.

	Animals/km^2										
	Summer				Fall						
BOEM (2014) Modeling Region	11	12	13	14	15	16	17	18	19	20	21
Mysticetes											
Minke whale	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003
Sei whale	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003
Bryde's whale	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003
Blue whale	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003
Fin whale	0.00003	0.00003	0.00015	0.00003	0.00003	0.00015	0.00003	0.00003	0.00003	0.00006	0.00003
North Atlantic right whale	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00017	0.00003
Humpback whale	0.00000	0.00000	0.00000	0.00000	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003
Odontocetes											
Common dolphin	0.01595	0.01595	0.05271	0.05271	0.01595	0.05580	0.01595	0.01595	0.01595	0.05271	0.01595
Pygmy killer whale	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003
Short-finned pilot whale	0.00035	0.01536	0.02665	0.00863	0.01536	0.00292	0.00070	0.02446	0.02863	0.00041	0.00050
Long-finned pilot whale	0.00012	0.00478	0.00382	0.00152	0.00513	0.00096	0.00023	0.00566	0.00274	0.00003	0.00003
Risso's dolphin	0.00017	0.02566	0.03236	0.01303	0.00035	0.02572	0.00026	0.00671	0.02630	0.00688	0.01303
Northern bottlenose whale	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003
Pygmy sperm whale	0.00009	0.00009	0.00009	0.00009	0.00009	0.00009	0.00009	0.00009	0.00009	0.00009	0.00009
Dwarf sperm whale	0.00023	0.00023	0.00023	0.00023	0.00023	0.00023	0.00023	0.00023	0.00023	0.00023	0.00023
Atlantic white-sided dolphin	0.00015	0.00015	0.00009	0.00009	0.00015	0.00015	0.00015	0.00012	0.00006	0.00015	0.00003
Fraser's dolphin	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003
Sowerby's beaked whale	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003
Blainville's beaked whale	0.00000	0.00061	0.00041	0.00000	0.00061	0.00082	0.00000	0.00061	0.00082	0.00000	0.00000
Gervais' beaked whale	0.00000	0.00061	0.00041	0.00000	0.00061	0.00082	0.00000	0.00061	0.00082	0.00000	0.00000
True's beaked whale	0.00000	0.00061	0.00041	0.00000	0.00061	0.00082	0.00000	0.00061	0.00082	0.00000	0.00000
Killer whale	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003
Melon-headed whale	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003
Harbor porpoise	0.00003	0.00003	0.00003	0.00003	0.00015	0.00015	0.00015	0.00012	0.00006	0.00015	0.00003
Sperm whale	0.00003	0.00534	0.00268	0.00003	0.00268	0.00536	0.00006	0.00006	0.00006	0.00003	0.00003
False killer whale	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003
Pantropical spotted dolphin	0.00650	0.00650	0.00650	0.00650	0.00650	0.00650	0.00650	0.00650	0.00650	0.00650	0.00650
Clymene dolphin	0.00309	0.00309	0.00309	0.00309	0.00309	0.00309	0.00309	0.00309	0.00309	0.00309	0.00309
Striped dolphin	0.00784	0.01609	0.06099	0.00968	0.01443	0.07749	0.00784	0.00784	0.00784	0.00784	0.00784
Atlantic spotted dolphin	0.00061	0.05452	0.05744	0.09236	0.00644	0.07198	0.00061	0.00061	0.00353	0.07782	0.05592
Spinner dolphin	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003
Rough-toothed dolphin	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015
Bottlenose dolphin	0.00522	0.07566	0.10974	0.07997	0.00863	0.08589	0.00522	0.08248	0.09954	0.05295	0.06656
Cuvier's beaked whale	0.00003	0.00431	0.00292	0.00003	0.00431	0.00574	0.00003	0.00431	0.00574	0.00003	0.00003
Pinnipeds											
Hooded seal	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Gray seal	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Harbor seal	0.00000	0.00000	0.00000	0.00003	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

three dimensions. The source also has variables describing its source operation over time, i.e., source level, signal duration, and pulse interval. Thus, it is possible to recreate the type of diving pattern that an animal shows in the real world. Furthermore, the movement of the animat can be programmed to respond to environmental factors, such as water depth and sound level (this latter feature was not used in this analysis). These responses to the environment are entitled 'aversions'. There are a number of potential aversion variables that can be used to build an animat's behavioral pattern. In this way, species that normally inhabit specific environments can be constrained in the model to stay within that habitat.

Once the behavior of the animats has been programmed, the model is run. The run consists of a user-specified number of steps forward in time. For each time step, each animat is moved according to the rules describing its behavior. For each time step of the model run, the received sound level at each receiver (i.e., marine mammal) animat is calculated. For this analysis, AIM predicts the movement patterns of the animats, and the received sound levels are calculated separately, using the acoustic propagation predictions provided by JASCO's acoustic propagation model, as described in Appendix A.

At the end of each time step, each animat evaluates its environment including its 3-D location, the time, and received sound level (if present). If an environmental variable has exceeded the user-specified boundary value (e.g., water too shallow), then the animat will alter its course to react to the environment.

The time history of acoustic exposure of each animat every 30 sec was analyzed to calculate (1) the maximum flat-weighted rms SPL received by each animat and (2) the maximum M-weighted rms SPL received by each animat, calculated separately for low-frequency (LF), mid-frequency (MF), and high-frequency (HF) cetaceans; M-weighting is a filter function that is applied to the acoustic signal to account for the differential hearing capabilities of different species groups (Southall et al. 2007). The M-weighted rms SPL values for individual received pulses were then converted into SEL units using JASCO-provided conversions, adjusted for the difference between modeling intervals (30 sec) and airgun shot intervals (20 sec) to determine the total energy to which an animal would be exposed during the survey (see Appendix B for a more detailed description).

The maximum rms received SPLs and accumulated SELs were then used to predict the number of modeled animats exposed at or above the following thresholds:

1. unweighted SPL of 160 dB re 1 μPa_{rms} (the "Level B" harassment criterion recognized by NMFS);
2. unweighted SPLs of 180 and 190 dB re 1 μPa_{rms} for cetaceans and pinnipeds, respectively (The traditional "Level A" harassment criterion recognized by NMFS);
3. accumulated SELs of 198 dB re 1 $\mu Pa^2 \cdot s$ for the three individually M-weighted groups of cetaceans and 186 dB re 1 $\mu Pa^2 \cdot s$ for pinnipeds (the energy-based injury criterion recommended by Southall et al. 2007).

The numbers exposed at this step are based upon the lengths of model lines and the modeled density of the animats. As a last step, these numbers were then scaled by the ratios of modeled line length to anticipated seismic line length and modeled densities to actual animal densities (see Table 3 in Appendix B).

As a result of the modeling methods, there are several important assumptions or caveats about the resulting estimates that should be noted. First, the calculated estimates assume any marine mammal sightings within or near the designated safety radii will not result in a shut down of seismic operations as a mitigation measure. Thus, the following estimates of the numbers of marine mammals potentially exposed to sounds at the various thresholds are precautionary, and probably overestimate the actual numbers of marine mammals that could be exposed since PSOs will be aboard the vessel to call for mitigation, as required. Second, it is important to understand that exposures were calculated for all survey lines within each modeling region during each season; however, survey activities will only occur on each survey line in one of the seasons. In other words, exposure estimates for each individual species will not be the sum of the values calculated for each season, but rather a value between the estimate for summer and fall. Third, the calculations assume that no cetaceans will move away from the trackline in response to increasing sound levels as the M/V *Discoverer* and towed airgun array approach, either prior to or after the received levels reach 160 dB re 1 μPa_{rms}. It is known that at least some species of baleen and toothed whales do move away from seismic sources (see § VII[a], and Appendix C [5]), with increasing avoidance as received levels increase.

Potential Number of Cetaceans Exposed to Various Received Sound Levels

The numbers of marine mammals that could be exposed to unweighted SPLs of 160 dB re 1 μPa_{rms} and 180 dB re 1 μPa_{rms} are given in Table 4 based on calculations of all survey lines being completed within each season; thus, the larger of the two season estimates for each species could be considered a maximum estimate and the request for take authorization. It would not be appropriate to sum the two season estimates as that would assume the survey would be completed twice (once in each season).

Estimates of exposure to SELs ≥198 dB re 1 $\mu Pa^2 \cdot s$ were also calculated using M-weighting functions to account for different hearing abilities among marine mammal species groups (Southall et al. 2007); however, the modeling indicated that no marine mammals were likely to accumulate a SEL ≥198 dB re 1 $\mu Pa^2 \cdot s$ (Appendix B). That is, based on the best available science and even in the absence of mitigation measures, modeling suggests there is no real chance of marine mammals being injured by seismic sounds produced during this survey. Results suggest some animals may occur within the unweighted 180 dB re 1 μPa_{rms} distance (Table 4); however the modeling assumes there will be no avoidance reactions by animals, does not account for mitigation measures being implemented (see § XI), and most of these animals are expected to be mid-frequency cetaceans, whose hearing is less-sensitive to the primarily low frequency energy contained in seismic sounds and therefore we do not anticipate and Level A takes. In addition, modeling results indicated no exposures at any threshold level for pinnipeds.

Number of Cetaceans that could be Exposed to SPLs ≥160 dB re 1 μPa_{rms}.— Numbers of cetaceans that could be exposed at SPLs ≥160 dB re 1 μPa_{rms} were estimated without using the M-weighting functions (i.e., flat weighted) for consistency with established standards from NMFS. The sound exposure modeling estimated that less than 4629 cetaceans could be exposed (in the absence of avoidance reactions and mitigation measures) to seismic sounds with received SPLs ≥160 dB re 1 μPa_{rms} (Table 4), most of which are delphinids (~88%). The total includes 132 exposures of endangered baleen whales (14 North Atlantic right whales, 2 humpback whales, and 8 fin whales, 62 blue whales, and 46 sei whales), and 27 sperm whales (3.2, 0.2, 0.2, 10, 2.2 and 1.7% of the regional populations, respectively).

Conclusions

The proposed seismic project will involve towing an airgun array that introduces pulsed sounds into the ocean. The survey will employ a 36-airgun array similar to the airgun arrays used for typical high-energy seismic surveys. The total airgun discharge volume will be ~6420 in^3. Routine vessel operations, other than the proposed airgun operations, are conventionally assumed not to affect marine mammals sufficiently to constitute "taking".

Avoidance reactions by several species of mysticetes to seismic vessels have been observed at ranges up to 6–8 km and occasionally as far as 20–30 km from the source vessel (see § VII below); however, reactions at the longer distances appear to be atypical of most species and situations. Odontocete reactions to seismic pulses, or at least the reactions of delphinids, are expected to extend to lesser distances than are those of mysticetes. At low frequencies, odontocete hearing is less sensitive than that of mysticetes, and delphinids are often seen from seismic vessels. In fact, there are documented instances of dolphins approaching active seismic vessels. However, delphinids as well as some other types of odontocetes sometimes show avoidance responses and/or other changes in behavior near operating seismic vessels.

Taking into account the mitigation measures that are planned (see § XI), effects on cetaceans are generally expected to be limited to avoidance of the area around the seismic operation and short-term

changes in behavior, falling within the MMPA definition of "Level B harassment". Furthermore, the estimated numbers of animals potentially exposed to sound levels sufficient to cause appreciable disturbance are generally low percentages of the regional population sizes. The estimates of the numbers of individuals that would be exposed to sounds ≥160 dB re 1 μPa_{rms} represent, for most species, <1% of the regional population.

Table 4. Precautionary estimates of the numbers of marine mammals that might be exposed to unweighted SPLs of 160 dB re 1 μPa_{rms} and 180 dB re 1 μPa_{rms} if the entire survey were completed within each season and assuming no avoidance or implementation of mitigation measures.

Species	Summer		Fall	
	160 dB_{rms} SPL	180 dB_{rms} SPL	160 dB_{rms} SPL	180 dB_{rms} SPL
Mysticetes				
Minke whale	0	0	6	1
Sei whale	46	8	17	3
Bryde's whale	167	13	136	10
Blue whale	62	6	43	2
Fin whale	8	2	4	1
North Atlantic right whale	0	0	14	2
Humpback whale	0	0	2	1
Odontocetes				
Common dolphin	426	37	159	21
Pygmy killer whale	1	0	1	0
Short-finned pilot whale	10	1	12	1
Long-finned pilot whale	3	1	7	1
Risso's dolphin	233	33	143	16
Northern bottlenose whale	1	1	1	1
Pygmy sperm whale	7	1	6	1
Dwarf sperm whale	134	8	82	6
Atlantic white-sided dolphin	2	1	2	1
Fraser's dolphin	93	3	67	6
Sowerby's beaked whale	3	1	3	1
Blainville's beaked whale	5	1	6	1
Gervais' beaked whale	7	1	7	1
True's beaked whale	17	3	20	3
Killer whale	1	0	6	2
Melon-headed whale	1	1	1	0
Harbor porpoise	5	2	7	2
Sperm whale	27	3	11	2
False killer whale	1	1	1	1
Pantropical spotted dolphin	56	8	39	6
Clymene dolphin	77	10	65	9
Striped dolphin	377	49	78	11
Atlantic spotted dolphin	660	75	139	21
Spinner dolphin	597	81	375	58
Rough-toothed dolphin	2	1	19	6
Bottlenose dolphin	1512	200	1001	105
Cuvier's beaked whale	32	4	25	2

The requested "take authorization" for each species is the estimated maximum number of individuals that could be exposed to ≥160 dB re 1 μPa_{rms} for any season. That figure likely overestimates (in some cases by a large margin) the actual number of animals that will be exposed to and will react to the seismic sounds. The reasons for that conclusion are outlined in the following section that describes the anticipated impacts to the species. The relatively short-term exposures are unlikely to result in any long-term negative consequences for the individuals or their populations. Since the sound exposure modeling based on SEL criteria indicated that, even in the absence of avoidance reactions, no cetaceans were likely to receive sufficient sound energy to incur auditory damage, no Level A takes are being requested.

The many cases of apparent tolerance by cetaceans of seismic exploration, vessel traffic, and some other human activities show that co-existence is possible. Mitigation measures such as pre-cruise planning, controlled speed, course alternation, look outs, non-pursuit, ramp ups, power downs or shut downs when marine mammals are seen within defined ranges, and special measures for species of particular concern, should further reduce short-term reactions, and avoid or minimize any auditory effects. In all cases, the effects are expected to be short-term, with no lasting biological consequence.

VII. ANTICIPATED IMPACT ON SPECIES OR STOCKS

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

The PEIS (BOEM 2014a) presented an impact analysis of geological and geophysical activities on cetaceans and pinnipeds based on a review of the potential effects of various sound sources on marine mammals. The following section includes a summary of the anticipated potential effects (or lack thereof) of the proposed seismic survey on marine mammals, with a focus on recent literature. A detailed review of noise effects on marine mammals, as well as information on the hearing abilities of marine mammals, were provided in the PEIS (BOEM 2014a; see § 4.2.2.2 and Appendix H).

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). Permanent hearing impairment, in the unlikely event that it occurred, would constitute injury, but temporary threshold shift (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. Recent research has shown that sound exposure can cause cochlear neural degeneration, even when threshold shifts and hair cell damage are reversible (Liberman 2013). These findings have raised some doubts as to whether TTS should continue to be considered a non-injurious effect.

Although the possibility cannot be entirely excluded, it is unlikely that the project would result in any cases of permanent hearing impairment, or any significant non-auditory physical or physiological effects. Some behavioral disturbance is expected, but this would be localized and short-term.

Tolerance

Numerous studies have shown that pulsed sounds from airguns are often detectable in the water at distances of many kilometers (e.g., Nieukirk et al. 2012). Appendix D of the PEIS provides a summary of

the characteristics of airgun pulses. 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 whales, 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. In general, pinnipeds usually seem to be more tolerant of exposure to airgun pulses than are cetaceans, with the relative responsiveness of baleen and toothed whales being variable.

Masking

Masking effects of pulsed sounds (even from large arrays of airguns) on marine mammal calls and other natural sounds are expected to be limited, although there are very 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), although situations with prolonged strong reverberation appear to be infrequent. Nonetheless, 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, 2013; Klinck et al. 2012), and this weaker reverberation presumably reduces the detection range of calls and other natural sounds to some degree. Guerra et al. (2013) 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 to 51% when a seismic survey was operating 450–2800 km away. Similarly, Wittekind et al. (2013) reported that airgun sounds may reduce the communication range of blue and fin whales 2000 km from the seismic source.

Although Nieukirk et al. (2012) and Blackwell et al. (2013) noted the potential for masking effects from seismic surveys on large whales, some whales are known to continue calling in the presence of seismic pulses (e.g., Cerchio et al. 2014; Nieukirk et al. 2012). Dolphins and porpoises are also commonly heard calling while airguns are operating (e.g., Gordon et al. 2004; Potter et al. 2007; Thompson et al. 2013). 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., Castellote et al. 2012; Blackwell et al. 2013). The hearing systems of baleen whales are undoubtedly more sensitive to low-frequency sounds than are the ears of the small odontocetes that have been studied directly (e.g., MacGillivray et al. 2014). The sounds important to small odontocetes are predominantly at much higher frequencies than are the dominant components of airgun sounds, thus limiting the potential for masking. In general, masking effects of seismic pulses are expected to be minor, given the normally intermittent nature of seismic pulses.

Disturbance Reactions

Disturbance includes a variety of effects, including subtle to conspicuous changes in behavior, movement, and displacement. Based on NMFS (2001, p. 9293), NRC (2005) and Southall et al. (2007), we assume that 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 cetaceans or pinnipeds or their populations.

Reactions to sound, if any, depend on species, state of maturity, experience, current activity, reproductive state, time of day, and many other factors (Richardson et al. 1995; Wartzok et al. 2004; Southall et al. 2007; Weilgart 2007; Ellison et al. 2012). If a marine mammal does react briefly to an underwater sound by changing its behavior or moving a small distance, the impacts of the change are unlikely to be significant to the individual, let alone the stock or population (e.g., New et al. 2013). 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 (e.g., Lusseau and Bejder 2007; Weilgart 2007). 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 mammals would be present within a particular distance of industrial activities and 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 might 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 humpbacks, gray whales (*Eschrichtius robustus*), bowheads (*Balaena mysticetus*), sperm whales, and ringed seals (*Pusa hispida*). Less detailed data are available for some other species of baleen whales, small toothed whales, and sea otters (*Enhydra lutris*), but for many species there are no data on responses to marine seismic surveys.

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

Studies of gray, bowhead, and humpback whales have shown that seismic pulses with received sound levels of 160–170 dB re 1 μPa_{rms} seem to cause obvious avoidance behavior in a substantial fraction of the animals exposed (Richardson et al. 1995). In many areas, seismic pulses from large arrays of airguns diminish to those levels at distances ranging from 4.5 to 14.5 km from the source. A substantial proportion of the baleen whales within those distances may show avoidance or other strong behavioral reactions to the airgun array. Subtle behavioral changes sometimes become evident at somewhat lower received levels, and some species of baleen whales, notably bowhead and humpback whales, at times show strong avoidance at received levels lower than 160–170 dB re 1 μPa_{rms}.

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 vessel; 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). The mean received level for initial avoidance of an approaching airgun was 140 dB re 1 μPa_{rms} for humpback pods containing females; however, some individual humpback whales, especially males, approached within distances of 100–400 m, where the

maximum received level was 179 dB re 1 μPa_{rms}. Studies examining the behavioral responses of humpback whales to airguns are currently underway off Eastern Australia (Cato et al. 2011, 2012, 2013).

In the Northwest Atlantic, humpback whale sighting rates were significantly greater during non-seismic periods compared with periods when a full array was operating, and humpbacks were more likely to swim away from a vessel during airgun operations (Moulton and Holst 2010). For humpback whales on their summer feeding grounds in southeast Alaska, there was no clear evidence of persistent avoidance when exposed to seismic pulses from a single airgun, despite the possibility of subtle effects, at received levels up to 172 re 1 μPa on an approximate rms basis (Malme et al. 1985). Similarly, there were no significant differences in encounter rates of wintering humpback whales off Angola when a 24-airgun array was operating vs. silent (Weir 2008). However, Cerchio et al. (2014) suggested that the breeding display of humpback whales off Angola may be disrupted by seismic sounds, as singing activity declined with increasing received levels. It has also 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 after allowance for data from subsequent years, there was "no observable direct correlation" between strandings and seismic surveys (IWC 2007:236).

There are no data on reactions of right whales to seismic surveys, but results from the closely-related bowhead whale 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 at received sound levels of ~120–130 dB re 1 μPa_{rms} (Miller et al. 1999; Richardson et al. 1999). However, more recent research on bowhead whales (Miller et al. 2005; Harris et al. 2007) corroborates earlier evidence that, during the summer feeding season, bowheads are not as sensitive to seismic sources; they typically begin to show avoidance reactions at received levels of about 152–178 dB re 1 μPa_{rms} (Richardson et al. 1986, 1995; Ljungblad et al. 1988; Miller et al. 2005). Nonetheless, Robertson et al. (2013) showed that bowheads on their summer feeding grounds exhibited subtle but statistically significant changes in surfacing–respiration–dive cycles during exposure to seismic sounds, including shorter surfacings, shorter dives, and decreased number of blows per surfacing.

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 of airgun pulses. 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_{rms}. Thus, bowhead whales in the Beaufort Sea apparently decrease their calling rates in response to seismic operations, although movement out of the area may also contribute to the lower call detection rate (Blackwell et al. 2013). 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.

Reactions of migrating and feeding (but not wintering) gray whales to seismic surveys have been studied. Malme et al. (1986, 1988) studied the responses of feeding eastern Pacific gray whales to pulses from a single 100-in^3 airgun off St. Lawrence Island in the northern Bering Sea. They estimated, based

on small sample sizes, that 50% of feeding gray whales stopped feeding at an average received pressure level of 173 dB re 1 μPa on an (approximate) rms basis, and that 10% of feeding whales interrupted feeding at received levels of 163 dB re 1 μPa_{rms} (Malme et al. 1986, 1988). Those findings were generally consistent with the results of experiments conducted on larger numbers of gray whales that were migrating along the California coast (Malme et al. 1984; Malme and Miles 1985), western Pacific gray whales feeding off Sakhalin Island, Russia (e.g., Gailey et al. 2007; Johnson et al. 2007; Yazvenko et al. 2007a,b), and gray whales off British Columbia (Bain and Williams 2006).

Various species of Balaenoptera (blue, sei, fin, and minke whales) have occasionally been reported in areas ensonified by airgun pulses. Sightings by observers on seismic vessels off the United Kingdom from 1997 to 2000 suggest that, during times of good sightability, sighting rates for mysticetes (mainly fin and sei whales) were similar when large arrays of airguns were operating vs. silent, although there was localized avoidance (Stone and Tasker 2006). Singing fin whales in the Mediterranean moved away from an operating airgun array, and their song notes had lower bandwidths during periods with versus 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 airgun array (Moulton and Holst 2010).

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 (Carretta et al. 2014), despite intermittent seismic exploration (and much ship traffic) in that area for decades. The western Pacific gray whale population did not seem affected by a seismic survey in its feeding ground during a previous year (Johnson et al. 2007). Similarly, bowhead whales have continued to travel to the eastern Beaufort Sea each summer, and their numbers have increased notably (see Allen and Angliss 2014), despite seismic exploration in their summer and autumn range for many years.

Toothed Whales.—Little systematic information is available on the reactions of toothed whales to sound pulses. However, there are systematic studies on sperm whales, and there is an increasing amount of information about responses of various odontocetes to seismic surveys based on monitoring studies. Seismic operators and PSOs 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). 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.

Preliminary findings of a monitoring study of narwhals (*Monodon monoceros*) 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). These findings do not seemingly support a suggestion by Heide-Jørgensen et al. (2013b) that seismic surveys in Baffin Bay may have delayed the migration timing of narwhals, thereby increasing the risk of narwhals to ice entrapment. The beluga (*Delphinapterus leucas*) 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; however, the animals tolerated high received levels of sound before exhibiting aversive behaviors (e.g., Finneran et al. 2000, 2002).

Results for porpoises depend on species. The limited available data suggest that harbor porpoises show stronger avoidance of seismic operations than do Dall's porpoises (*Phocoenoides dalli*) (Bain and Williams 2006; Stone and Tasker 2006). 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 $\mu Pa^2 \cdot s$); however, animals returned to the area within a few hours. This apparent difference in responsiveness of these two porpoise species is consistent with their relative responsiveness to boat traffic and some other acoustic sources (Richardson et al. 1995; Southall et al. 2007).

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; Weir 2008; Moulton and Holst 2010), but foraging behavior can be altered upon exposure to airgun sound (e.g., Miller et al. 2009). 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). However, northern bottlenose whales continued to produce high-frequency clicks when exposed to sound pulses from distant seismic surveys (e.g., Simard et al. 2005). In any event, it is likely that beaked whales would also show strong avoidance of an approaching seismic vessel, although this has not been documented explicitly.

Pinnipeds.—Pinnipeds are not likely to show a strong avoidance reaction to an airgun array. Visual monitoring from seismic vessels has shown only slight (if any) avoidance of airguns by pinnipeds and only slight (if any) changes in behavior. However, telemetry work has suggested that avoidance and other behavioral reactions may be stronger than evident to date from visual studies (Thompson et al. 1998b).

Conclusions.—Cetacean 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, belugas, and harbor porpoises. A ≥170 dB re 1 μPa_{rms} disturbance criterion (rather than ≥160 dB) would appear to be more appropriate for delphinids and pinnipeds, which tend to be less responsive than other marine mammals.

Hearing Impairment

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 in Southall et al. 2007). However, there has been no specific documentation of TTS let alone permanent hearing damage, i.e., permanent threshold shift (PTS), in free-ranging marine mammals exposed to sequences of airgun pulses during realistic field conditions.

Current NMFS policy regarding exposure of marine mammals to high-level sounds is that cetaceans and pinnipeds should not be exposed to impulsive sounds with received levels ≥180 and 190 dB re 1 μPa_{rms}, respectively (NMFS 2000). Those criteria have been used in establishing the shut-down zones planned for the proposed seismic survey. However, those criteria were established before there was any information about minimum received levels of sounds necessary to cause auditory impairment in marine mammals.

Recommendations for science-based noise exposure criteria for marine mammals, frequency-weighting procedures, and related matters were published by Southall et al. (2007). Those recom-

mendations have not yet been formally adopted by NMFS for use in regulatory processes and during mitigation programs associated with seismic surveys, although some aspects of the recommendations have been taken into account in certain environmental impact statements and small-take authorizations. NMFS is currently drafting new acoustic guidance and procedures for calculating noise exposure to marine mammals taking at least some of the Southall et al. recommendations into account (NOAA 2013b). The new acoustic guidance and procedures will account for the now-available scientific data on marine mammal TTS, the expected offset between the TTS and PTS thresholds, differences in the acoustic frequencies to which different marine mammal groups are sensitive (e.g., M-weighting or generalized frequency weightings for various groups of marine mammals, allowing for their functional bandwidths), and other relevant factors.

Nowacek et al. (2013) 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 (see § XI, "MITIGATION MEASURES). In addition, many cetaceans and (to a limited degree) pinnipeds 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 will reduce or (most likely) avoid any possibility of hearing impairment.

Temporary Threshold Shift (TTS).—TTS is the mildest form of hearing impairment that can occur during exposure to a strong sound (Kryter 1985). While experiencing TTS, the hearing threshold rises and a sound must be stronger in order to be heard. The magnitude of TTS depends on the level and duration of noise exposure and frequency, among other considerations (Kryter 1985; Richardson et al. 1995; Southall et al. 2007). For sound exposures at or somewhat above the TTS threshold, hearing sensitivity recovers rapidly after exposure to the noise ends.

Available data on TTS in marine mammals are summarized in Southall et al. (2007) and in BOEM (2014a; § 4.2.2.2 and Appendix H). The majority of these data concern non-impulse sound, but there are limited published data concerning TTS onset upon exposure to impulses from a watergun or airgun (e.g., Finneran et al. 2002; Lucke et al. 2009). None of the published data concern TTS elicited by exposure to multiple pulses of sound during operational seismic surveys (Southall et al. 2007). Recent information corroborates earlier expectations that the effect of exposure to strong transient sounds is closely related to the total amount of acoustic energy that is received (Finneran et al. 2005). However, the assumption that, in marine mammals, the occurrence and magnitude of TTS is a function of cumulative acoustic energy (SEL) is probably an oversimplification (Finneran 2012). Several studies have shown results that were not fully consistent with an equal-energy model to predict TTS onset; that is, 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 (e.g., Kastak et al. 2005; Mooney et al. 2009a,b; Popov et al. 2011). Kastelein et al. (2012a,b; 2013b) also reported that the equal energy model is not valid for predicting TTS in harbor porpoise or harbor seals, and Supin et al. (2013) reported that SEL may not be a valid metric for examining fatiguing sounds on beluga whales.

The TTS threshold for odontocetes exposed to a single impulse from a watergun (Finneran et al. 2002) appeared to be somewhat lower than for exposure to non-impulse sound. This was expected, based on evidence from terrestrial mammals showing that broadband pulsed sounds with rapid rise times have greater auditory effect than do non-impulse sounds (Southall et al. 2007). The received energy level of a single seismic pulse (with no frequency weighting) that caused the onset of mild TTS in the beluga, was

~186 dB re 1 μPa^2 · s (Finneran et al. 2002)[2]. The rms level of an airgun pulse (in dB re 1 μPa measured over the duration of the pulse) is typically 10–15 dB higher than the SEL for the same pulse when received within a few kilometres of the airguns (Greene 1997; McCauley et al. 1998, 2000; Appendix A). Thus, a single airgun pulse might need to have a received level of ~196–201 dB re 1 μPa$_{rms}$ in order to produce brief, mild TTS. Exposure to several strong seismic pulses that each have received levels near 190 dB re 1 μPa$_{rms}$ (175–180 dB SEL) could result in cumulative exposure of ~186 dB SEL (flat-weighted) or ~183 dB SEL (M_{mf}-weighted), and thus slight TTS in a small odontocete. The distances from the proposed airgun array at which the received energy level (per pulse, flat-weighted) is expected to be ≥190 dB re 1 μPa$_{rms}$ are 480 m, 450 m, and 440 m from the airgun array in shallow-, intermediate-, and deep water areas, respectively (Table 1). For an odontocete closer to the surface, the maximum radius with ≥190 dB re 1 μPa$_{rms}$ would be smaller.

However, this assumes that the TTS threshold upon exposure to multiple pulses is (to a first approximation) a function of the total received pulse energy, without allowance for any recovery between pulses. Recent data, however, 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). Schlundt et al. (2013) reported that the potential for seismic surveys using airguns to cause auditory effects on dolphins may be lower than previously thought. Based on behavioral tests, Finneran et al. (2011) and Schlundt et al. (2013) reported no measurable TTS in bottlenose dolphins after exposure to 10 impulses from a seismic airgun with a cumulative SEL of ~195 dB re 1 μPa^2 · s; results from AEP measurements were more variable (Schlundt et al. 2013).

The conclusion that the TTS threshold is higher for non-impulse sound than for impulse sound is somewhat speculative. The available TTS data for a beluga whale exposed to impulse sound are extremely limited, and the TTS data from the beluga whale and bottlenose dolphin exposed to non-pulse sound pertain to sounds at 3 kHz and above. Follow-on work has 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 to 30 min at frequencies of 11.2 to 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. 2013a). Popov et al. (2013b) also 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, Nachtigall and Supin (2013) reported that false killer whales are able to change their hearing sensation levels when exposed to loud sounds, such as warning signals or echolocation sounds.

The above TTS information for odontocetes is mainly derived from studies on the bottlenose dolphin and beluga. Some cetaceans may incur TTS at lower sound exposures than are necessary to elicit TTS in the beluga or bottlenose dolphin. For a harbor porpoise, the received level of airgun sound that elicited onset of TTS was lower (Lucke et al. 2009). Thus, it is inappropriate to assume that onset of TTS occurs at similar received levels in all cetaceans (*cf.* Southall et al. 2007). Based on the best available information, Southall et al. (2007) recommended a TTS threshold for exposure to single or multiple pulses of 183 dB re 1 μPa^2 · s for all cetaceans. Tougaard et al. (2013) proposed a TTS criterion of 165

[2] If the low frequency components of the watergun sound used in the experiments of Finneran et al. (2002) are downweighted as recommended by Southall et al. (2007) using their Mmf-weighting curve, the effective exposure level for onset of mild TTS was 183 dB re 1 μPa^2 · s (Southall et al. 2007).

dB re 1 μPa^2·s (unweighted) for porpoises based on data from two recent studies. In addition, initial evidence from more prolonged (non-pulse and pulse) sound exposures suggests 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. 2005, 2008; Kastelein et al. 2013b). The TTS threshold for pinnipeds for pulsed sounds has been indirectly estimated at an SEL of ~171 dB re 1 μPa^2·s (Southall et al. 2007), which would be equivalent to a single pulse with received level ~181–186 dB re 1 μPa$_{rms}$, or a series of pulses for which the highest rms values are a few dB lower. However, pinnipeds are unlikely to be encountered during the planned project.

For baleen whales, there are no data, direct or indirect, on levels or properties of sound that are required to induce TTS. The frequencies to which baleen whales are most sensitive are assumed to be lower than those to which odontocetes are most sensitive, and natural background noise levels at those low frequencies tend to be higher. As a result, auditory thresholds of baleen whales within their frequency band of best hearing are believed to be higher (less sensitive) than are those of odontocetes at their best frequencies (Clark and Ellison 2004). Based on this, Southall et al. (2007) suspected that received levels causing TTS onset may also be higher in baleen whales. However, based on data from Finneran and Schlundt (2010) that showed lower TTS onset values during exposure to non-impulse sound in the region of best hearing sensitivity for mid-frequency cetaceans, as well as other considerations, Wood et al. (2012) suggested that received levels from multiple pulses (e.g., airgun sounds) that may cause auditory impairment in low-frequency cetaceans may also be lower. Gedamke et al. (2011) suggested that some baleen whales whose closest point of approach to a seismic vessel is 1 km or more could experience TTS.

Additional data are needed to determine the received sound levels at which cetaceans 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, although there is recent evidence that auditory effects in a given animal are not a simple function of received acoustic energy. Frequency, duration of the exposure, and occurrence of gaps within the exposure can influence the auditory effect (Finneran and Schlundt 2010, 2011, 2013; Finneran et al. 2010a,b; Finneran 2012; Ketten 2012; Kastelein et al. 2013a).

In any event, few if any cases of TTS are expected given the strong likelihood that most cetaceans would avoid the approaching airguns (or vessels) before being exposed to levels high enough for there to be any possibility of TTS and the mitigation measures that are planned, such as ramp-up. The ramp-up (soft-start) procedure is used when commencing airgun operations, to give marine mammals near the vessel the opportunity to move away before they are exposed to sound levels that might be strong enough to elicit TTS.

NMFS (1995, 2000) concluded that cetaceans and pinnipeds should not be exposed to pulsed underwater noise at received levels exceeding 180 and 190 dB re 1 μPa$_{rms}$, respectively. Those sound levels are ***not*** considered to be the levels above which TTS might occur. Rather, they were the received levels above which, in the view of a panel of bioacoustics specialists convened by NMFS before TTS measurements for marine mammals started to become available, one could not be certain that there would be no injurious effects, auditory or otherwise, to marine mammals. As summarized above and in Southall et al. (2007) and BOEM (2014a; Appendix H), data that are now available imply that TTS is unlikely to

occur in most odontocetes (or mysticetes) unless they are exposed to a sequence of several airgun pulses stronger than 190 dB re 1 μPa_{rms}. On the other hand, for the harbor seal and any species with similarly low TTS thresholds (possibly including the harbor porpoise), TTS may occur upon exposure to one or more airgun pulses whose received level equals the NMFS "do not exceed" value, for pinnipeds, of 190 dB re 1 μPa_{rms}. That criterion corresponds to a single-pulse SEL of 175–180 dB re 1 $\mu Pa^2 \cdot s$ in typical conditions, whereas TTS is suspected to be possible (in harbor seals) with a cumulative SEL of ~171 dB re 1 $\mu Pa^2 \cdot s$.

Permanent Threshold Shift (PTS).—When PTS occurs, there is physical damage to the sound receptors in the ear. In severe cases, there can be total or partial deafness, while in other cases, the animal or human has an impaired ability to hear sounds in specific frequency ranges (Kryter 1985). 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 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 (Richardson et al. 1995, p. 372*ff*). 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).

Based on data from terrestrial mammals, a precautionary assumption is that the PTS threshold for impulse sounds (such as airgun pulses as received close to the source) is at least 6 dB higher than the TTS threshold on a peak-pressure basis, and probably >6 dB (Southall et al. 2007). On an SEL basis, Southall et al. (2007, p. 441-4) estimated that received levels would need to exceed the TTS threshold by at least 15 dB for there to be risk of PTS. Thus, for all cetaceans they estimate that the PTS threshold might be an M-weighted SEL (for the sequence of received pulses) of ~198 dB re 1 $\mu Pa^2 \cdot s$ (15 dB higher than the TTS threshold for an impulse), where the SEL value is cumulated over the sequence of pulses. However, Wood et al. (2012) presented revised thresholds for low-frequency (192 dB re 1 $\mu Pa^2 \cdot s$) and high-frequency cetaceans (179 dB re 1 $\mu Pa^2 \cdot s$) based on information from newer studies as well as other considerations. Additional assumptions had to be made to derive a corresponding estimate for pinnipeds, as the only available data on TTS-thresholds in pinnipeds pertain to non-impulse sound. Southall et al. (2007) estimate that the PTS threshold could be a cumulative M_{pw}-weighted SEL of ~186 dB re 1 $\mu Pa^2 \cdot s$ in the harbor seal exposed to impulse sound. The PTS threshold for the California sea lion (*Zalophus californianus*) and northern elephant seal (*Mirounga angustirostris*) would probably be higher, given the higher TTS thresholds in those species. (Again, pinnipeds are unlikely to be encountered in the planned project.)

Southall et al. (2007) also note that, regardless of the SEL, there is concern about the possibility of PTS if a cetacean or pinniped received one or more pulses with peak pressure exceeding 230 or 218 dB re 1 μPa (peak), respectively. A peak pressure of 230 dB re 1 μPa (3.2 bar · m, 0-pk) would only be found within a few meters of the largest airguns in the planned airgun array (Caldwell and Dragoset 2000). A peak pressure of 218 dB re 1 μPa could be received somewhat farther away; to estimate that specific distance, one would need to apply a model that accurately calculates peak pressures in the near-field around an array of airguns.

Given the higher level of sound necessary to cause PTS as compared with TTS, it is considerably less likely that PTS would occur. Baleen whales generally avoid the immediate area around operating seismic vessels, as do some other marine mammals. The planned monitoring and mitigation measures, including visual monitoring and shut downs of the airguns when mammals are seen within or approaching the exclusion zone, will further reduce the probability of exposure of marine mammals to sounds strong enough to induce PTS.

Strandings and Mortality

Strong transient sounds have the potential to cause direct or indirect physical injury to marine mammals, which might result in death, in situation-specific circumstances (see BOEM 2014a; § 4.2.2.2). The association of mass strandings of beaked whales with naval mid-frequency sonar has raised the possibility that beaked whales exposed to strong sounds may be especially susceptible to injury and/or behavioral reactions that can lead to stranding (e.g., Hildebrand 2005; Cox et al. 2006; Southall et al. 2007). This suggests that caution is warranted when dealing with exposure of marine mammals to any repeated, high-intensity transient sounds (Hildebrand 2005).

Specific sound-related processes that lead to strandings and mortality are not well documented, but may include (1) swimming in avoidance of a sound into shallow water; (2) a change in behavior (such as a change in diving behavior) that might contribute to tissue damage, gas bubble formation, hypoxia, cardiac arrhythmia, hypertensive hemorrhage or other forms of trauma; (3) a physiological change such as a vestibular response leading to a behavioral change or stress-induced hemorrhagic diathesis, leading in turn to tissue damage; and (4) tissue damage directly from sound exposure, such as through acoustically mediated bubble formation and growth or acoustic resonance of tissues. There are increasing indications that gas-bubble disease (analogous to "the bends"), induced in supersaturated tissue by a behavioral response to acoustic exposure, could be a pathologic mechanism for the strandings and mortality of some deep-diving cetaceans exposed to sonar. However, the evidence for this remains circumstantial and associated with exposure to naval mid-frequency sonar, not seismic surveys (Cox et al. 2006; Southall et al. 2007; Kvadsheim et al. 2012).

Seismic pulses and mid-frequency sonar signals are quite different, and there is no specific evidence that they can cause serious injury, death, or stranding even in the case of large airgun arrays. Airgun pulses are less energetic, broadband impulses with most of the energy below 1 kHz, and slower rise times than sonar systems. Typical military mid-frequency sonars emit non-impulse sounds at frequencies of 2–10 kHz, generally with a relatively narrow bandwidth at any one time. Thus, it is not appropriate to assume that there is a direct connection between the effects of military sonar and seismic surveys on marine mammals. One of the hypothesized mechanisms by which naval sonars lead to strandings might, in theory, also apply to seismic surveys: If the strong sounds sometimes cause deep-diving species to alter their surfacing–dive cycles in a way that causes bubble formation in tissue, that hypothesized mechanism might apply to seismic surveys as well as mid-frequency naval sonars. However, there is no specific evidence of this upon exposure to airgun pulses.

There is no conclusive evidence of cetacean strandings or deaths at sea as a result of exposure to seismic surveys, but a few cases of strandings in the general area where a seismic survey was ongoing have led to speculation concerning a possible link between seismic surveys and strandings (e.g., Castellote and Llorens 2013). A mass mortality of dolphins on the coast of Peru was originally potentially attributed to a seismic survey, virus or pathogen (Fraser and Environmental Health News, 2012); however, it was not possible to link the mortality event to offshore seismic surveys. Suggestions that there was a link between seismic surveys and strandings of humpback whales in Brazil (Engel et al.

2004) were not well founded (IAGC 2004; IWC 2007). In Sept. 2002, there was a stranding of two Cuvier's beaked whales in the Gulf of California, Mexico, when the Lamont Doherty Earth Observatory vessel R/V *Maurice Ewing* was operating a 20-airgun, 8490-in^3 airgun array in the general area. The link between the stranding and the seismic surveys was inconclusive and not based on any physical evidence (Hogarth 2002; Yoder 2002). The ship was also operating its multibeam echosounder at the same time, but this likely had less potential than the aforementioned naval sonars to affect beaked whales, given its downward-directed beams, much shorter pulse durations, and lower duty cycle.

No injuries of beaked whales or other marine mammals are anticipated during the proposed study because of (1) the high likelihood that any marine mammals nearby would avoid the approaching vessel before being exposed to high sound levels, (2) the proposed monitoring and mitigation measures, including avoiding submarine canyons, where deep-diving species may congregate, and (3) differences between the planned airgun sound and the sonar sounds involved in the naval exercises associated with strandings.

Non-auditory Physiological Effects

Sound is a potential source of stress for marine mammals (e.g., Wright et al. 2011), but available data on potential stress-related impacts of anthropogenic noise on marine mammals are limited. Most recently, 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.

Aside from stress, other types of physiological effects might, in theory, be involved in beaked whale strandings upon exposure to naval sonar (Cox et al. 2006). However, resonance (Gentry 2002) and direct noise-induced bubble formation (Crum et al. 2005) are not expected in the case of an impulsive source like an airgun array. 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.

In general, very little is known about the potential for seismic survey sounds (or other types of strong underwater sounds) to cause non-auditory physical effects in marine mammals. Such effects, if they occur at all in association with seismic surveys, would presumably be limited to short distances and to activities that extend over a prolonged period in a given area. The available data do not allow identification of a specific exposure level above which non-auditory effects can be expected (Southall et al. 2007), or any meaningful quantitative predictions of the numbers (if any) of marine mammals that might be affected in those ways. 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. Also, the brief duration of exposure of any given mammal, the deep water in most of the study area, and the planned monitoring and mitigation measures (§ XI) would further reduce the probability of exposure of marine mammals to sounds strong enough to induce non-auditory physical effects.

Possible Effects of Other Acoustic Sources

Navigational echosounders and a pinger would also be operated from the vessels during the proposed survey. Details on different types of echosounders can be found in Appendix D of the PEIS (BOEM 2014a).

Information regarding the potential effects of echosounders on marine mammals is limited. Although there has been a recent scientific review linking the operation of a 12-kHz multibeam echsounder to a mass stranding of melon-headed whales off Madagascar, unequivocal conclusion on causality of the event was limited because of a lack of information about the event and a number of potentially contributing factors (Southall et al. 2013). The independent review panel report indicated that this incident was likely the result of a complicated confluence of environmental, social and other factors that have a very low probability of occurring again in the future, but recommended that the potential be considered in environmental planning.

Frankel (2005) reported that migrating gray whales reacted to a 21–25 kHz "whale-finding" sonar (source level of 215 dB re 1 μPa · m) by orienting slightly away from the source and being deflected from their course by ~200 m. These responses were not obvious in the field and were only determined later during data analysis. Gerrodette and Pettis (2005) assessed odontocete reactions to an echosounder and an Acoustic Doppler Current Profiler (ADCP) operated from oceanographic vessels in the Eeastern Tropical Pacific. Results indicated that when the echosounder and ADCP were on, spotted and spinner dolphins were detected slightly more often and beaked whales less often during visual surveys (Gerrodette and Pettis 2005). Baleen whales showed no significant responses when the echosounder and ADCP were transmitting (Gerrodette and Pettis 2005). Sperm whales usually continued calling and did not appear to otherwise react to continual pulsing from echosounders, e.g., at 12 kHz (Backus and Schevill 1966; Watkins 1977).

BOEM (2014a) determined that non-airgun sound sources used during seismic surveys would be expected have a minor impact on marine mammals. In addition, the PEIS considered single beam echosounders to have negligible sound field levels compared to other acoustic sources, because of the narrow beam width that is directed straight down (BOEM 2014a, Appendix D). Thus, the single-beam echosounder is not likely to impact marine mammals (1) given the lower acoustic exposures relative to airguns and (2) because the intermittent and/or narrow downward-directed nature of its sounds would result in no more than one or two brief signal exposures of any individual marine mammal given the movement and speed of the vessel.

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 relevant subsistence hunting for marine mammals off the U.S. east coast, so the proposed activities will 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 will 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 will be temporarily elevated noise levels and the associated direct effects on marine mammals, as discussed in § VII, above.

The hearing abilities of marine invertebrates (crustaceans and cephalopods) and marine fish, as well as the effects of sound on marine invertebrates, fish, and their fisheries were discussed in the PEIS (BOEM 2014a; § 4.2.5 and Appendix J). Sound produced by seismic airguns could cause physiological effects, injury, and perhaps mortality to an insignificant number of some fish species, particularly larval and egg stages, if the animals are in extreme proximity to the airgun source. However, no population-level effects on invertebrates would be expected given the restricted zone of pathological effects. Similarly, airgun sound could potentially disturb fish close to airgun sources. To be significant, such behavioral changes would have to result in an overall reduction in the health, abundance, or catchability of a species of concern at the population level. In general, the temporal and spatial scale of disturbance effects on marine fish would likely be short-term and limited to the localized area immediately surrounding an active airgun. Because seismic surveys are typically conducted on relatively small spatial scales (e.g., on closely spaced transects in small areas) or temporal scales (e.g., basin-wide surveys with transects far apart where activites occur in any given location for ony a brief period of time, such as the proposed survey), significant effects at the population level are not expected. Therefore, the operations are not expected to cause significant impacts on habitats used by marine mammals, or on the food sources that marine mammals use.

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 effects of the planned activity on marine mammal habitats and food resources are expected to be negligible, as described above. Because operations at any single location within the survey area will be limited in duration, the proposed activity is not expected to have any habitat-related effects that could cause significant or long-term consequences for individual marine mammals or their populations, However, a small minority of the marine mammals that are present near the survey vessel may be temporarily displaced as much as a few kilometers as the vessel transits through the area.

During the proposed survey, marine mammal habitats defined generally as shelf, slope, and pelagic waters will be exposed to intermittent seismic survey sounds. High concentrations of marine mammals and/or marine mammal prey species are not expected in the proposed survey area. Although there are right whale calving and nursery grounds as well as migration areas located near the proposed survey area, the planned survey lines do not overlap these areas. Additionally, right whales are typically present in these areas from November through April, mostly outside of the temporal window of the project. There is no critical habitat for any marine mammal species within the proposed survey area. The nearest planned survey line is, at it's closest point, ~27 km from the North Atlantic right whale southeast U.S. critical habitat area in coastal waters of Georgia and Florida.

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.

Various species of marine mammals and sea turtles are expected to be encountered during the proposed seismic surveys. To minimize impacts to these species, airgun operations will be conducted in accordance with NMFS and the USFWS requirements under the MMPA and the ESA. Additionally, BOEM (2014a) identified several subjects and areas relevant to ION's planned survey where guidance would be provided to minimize potential impacts from the operation including: vessel strike avoidance (additional details below), marine debris awareness, avoidance of sensitive seafloor resources, operating in or near national marine sanctuaries, and coordinating with the military and NASA. ION will conduct or adhere to all relevant guidance provided by BOEM with regard to the planned survey. The following subsections describe mitigation measures that are an integral part of ION's planned seismic survey.

Planning Phase

In designing this proposed seismic survey, ION has considered potential environmental impacts including seasonal, biological, and weather factors; ship schedules; and equipment availability. This includes using the smallest airgun source possible to meet the survey objectives. Most important was conducting a preliminary assessment of the entire survey area including preparing descriptions of all marine mammal and sea turtle species that could be encountered during the survey, focused on their geographical and seasonal distributions. Based on those seasonal distribution maps and operational considerations such as vessel scheduling and availability, ION planned to conduct the survey during the July–December period.

Vessel Strike Avoidance

BOEM (2014a) described a number of measures intended to reduce the chance of vessels striking and injuring marine mammals and sea turtles while operating in the region. These measueres included:

- Maintaining a watch for marine mammals and sea turtles and slowing down or stopping vessels to avoid striking protected species.
- Complying with speed restrictions (≤10 knots) in North Atlantic right whale management areas including critical habitat, Seasonal Management Areas (SMAs), and active Dynamic Management Areas (DMAs).
- Reducing vessel speeds to 10 knots when mother/calf pairs, pods, or large assemblages of cetaceans are observed.
- Maintaining >500 m distance from North Atlantic right whales; if a right whale comes within 100 m, then shutting down the engines or propulsion.
- Maintaining >100 m from all Endangered Species Act listed species.
- Maintaining >50 m from all other marine mammals and sea turtles.
- Report sightings of all dead or injured marine mammals or sea turtles within 24 hrs.

ION's survey vessels will, to the extent practicable while ensuring crew and vessel safety, follow such guidance as provided by NMFS or BOEM.

Seismic Source Mitigation During Operations

Proposed mitigation measures when using the airgun array are described in the following sections. ION understands that the final mitigation measures and protocols will be determined thorugh the application review process and provided in the authorization issued by NMFS.

Proposed Safety Radii

Empirical measurements of sounds from the planned 36-airgun array do not exist. Received sound levels from the source in relation to distance and direction were modeled by JASCO at 18 sites in the survey area. Summary and detailed descriptions of the modeling effort are provided in § I and Appendix A, respectively. Based on the modeling, estimates of the maximum distances from the airgun array where flat-weighted sound pressure levels of 190, 180, 170, and 160 dB re 1 μPa_{rms} are predicted to be received in three depth ranges (>100 m, 100–1000 m, and >1000 m) and both seasons are shown in Table 5.

During reduced power operations, such as turns between survey lines, during brief equipment maintenance, or power downs for marine mammals observed within the exlusion zone of the full airgun array, a single 40 in^3 airgun will continue operating. BOEM (2014a) included acoustic propagation modeling results for a 2-airgun, 90 in^3 source that showed the expected 180-dB re 1 μPa_{rms} distance to be between 74 m and 177 m, depending on season and location. Measurements of a 4x10 in^3 array were made at various locations offshore Alaska and distances to the 180-dB re 1 μPa_{rms} threshold ranged from 99 m to 160 m (NOAA 2013a). A single airgun of 40 in^3 will have a smaller acoustic footprint than either of the two source described above, but as a cautionary approach, a 150 m exclusion zone will be enforced around the single operating 40 in^3 airgun.

Draft guidance for noise exposure criteria were published recently (NOAA 2013b) largey based on earlier work by Southall et al. (2007) with some important updates. ION will be prepared to revise its procedures for estimating numbers of mammals "taken", exclusion zones, etc., when those guidelines are finalized.

Pre-Startup Observations

A 30-minute pre-startup watch has routinely been applied in the Gulf of Mexico under Joint NTL 2012-G02 (USDOI, BOEM and BSEE 2012), for seismic surveys authorized by NMFS in Alaska (e.g. NMFS 2013), and for seismic surveys worldwide conducted by NSF and USGS (e.g. NSF and USDOI-USGS 2011) including recently in the U.S. Atlantic (NMFS 2014). Seismic surveys conducted using a 30 minutes pre-startup watch and ramp up procedures have not resulted in any known injuries or mortalities to marine mammals. As described in Appendix E of BOEM (2014a) and summarized in the associated Biological Assessment, the dive times for most species likely to be encountered typically range from 1–20 minutes with surface intervals lasting from less than one minute to a few minutes. For those reasons, a 30-minute pre-startup watch is planned for use during the proposed seismic survey.

Qualified, third-party Protected Species Observers (PSOs) will conduct observations of the appropriate 180-dB re 1 μPa_{rms} safety radius for a minimium of 30 minutes prior to the start of airgun operations when no airgun activity has occurred for >20 minutes and PSOs have discontinued observations. The entire radius must be visible and free of marine mammals for the entire 30 minutes in order for airgun activity to begin. Airgun activity will not resume until the animal has cleared the safety zone. The animal will be considered to have cleared the safety zone if it

- is visually observed to have left the safety radius, or
- has not been seen within the zone for 15 min in the case of small odontocetes and sea turtles, or
- has not been seen within the zone for 30 min in the case of mysticetes and large odontocetes, including sperm, pygmy sperm, dwarf sperm, and beaked whales.

Table 5. Modeled distances to which sound pressure levels ≥180 dB re 1 μPa_{rms} (flat-weighted) could be received in shallow (<100 m), intermediate (100–1000 m), and deep

(>1000 m) water from the 6420 in^3 36-airgun array planned for use during the planned seismic survey in summer (July–September) and fall (October–December) 2016 (Appendix A).

Season	Water Depth	Modeled 180 dB_{rms} Radii (km)
Summer	Deep	1.88
	Intermediate	1.71
	Shallow	1.11
Fall	Deep	1.89
	Intermediate	1.72
	Shallow	1.12

The use of a towed passive acoustic system (see below) will allow the 30-minute pre-startup watch to be accomplished during periods of poor visibility (darkness, fog, etc.)

Ramp-up Procedures

A ramp-up procedure will be followed when the airgun array first begins operating and after any period of more than 20 minutes without full array activity. Ramp up will begin with the smallest airgun in the array (40 in^3). Airguns will be added in a sequence such that the source level of the array will increase gradually over the course of 20–40 minutes. During ramp-up, the PSOs will monitor the safety radius and if marine mammals or sea turtles are sighted a power down or shut down will be implemented as though the full array were operational.

If the complete safety zone has not been visible for at least 30 minutes prior to the start of operations, ramp up will not commence unless at least one airgun (40 in^3) has been operating during the interruption of seismic survey operations or passive acoustic monitoring has been in use. If one airgun has operated during a reduced-power period or passive acoustic montoring has had no detections within the safety radius in the previous 30 minutes, then ramp up to full power will be permissible at night or in poor visibility.

Speed or Course Alteration

If a marine mammal or sea turtle is detected outside the safety radius and, based on its position and the relative motion, is likely to enter the safety radii, the vessel's speed and/or course may be changed. This is rarely practicable, but could be performed under some circumstances. The activities and movements of the marine mammal or sea turtle (relative to the seismic vessel) will then be closely monitored to determine whether the animal is approaching the applicable safety radius. If the animal appears likely to enter the safety radius, further mitigative actions will be taken, i.e., either further course alterations or a power down or shut down of the airguns. Typically, during seismic operations, the source vessel is unable to change speed or course and one or more alternative mitigation measures (see below) will need to be implemented.

Power-down Procedures

A power-down involves decreasing the number of airguns in use such that the radius of the 180-dB zone is decreased to the extent that marine mammals or sea turtles are no longer in or about to enter the safety radius. A power-down of the airgun array can also occur when the vessel is moving from one

survey line to another or during unscheduled, unavoidable maintenance of the airgun array. Power-downs have been routinely applied as mitigation during seismic surveys operating under IHAs issued by NMFS. During a power-down, one 40-in^3 airgun will be operated. The continued operation of one airgun is intended to alert marine mammals and turtles to the continued presence of the seismic survey activity in the area.

If a marine mammal or sea turtle is detected within or about to enter the safety radius of the full array, and if the vessel's speed and/or course cannot be changed to avoid having the animal enter the safety radius, the array will be powered down to a single airgun firing on the same interval used during seismic data collection. Likewise, if a mammal or sea turtle is already within the safety zone when first detected, the airguns will be powered down immediately if they would then be outside of the safety radius of the single airgun. If a marine mammal or sea turtle is detected within or near the smaller safety radius around that single airgun (150 m), it will be shut down (see next subsection). The airgun array will not be powered down for delphinids that voluntarily approach the survey vessel or airgun array in a "clear and purposeful approach toward the vessel with a speed and vector that indicates the delphinid(s) is approaching the vessel and remains near the vessel or towed equipment" (BOEM 2014a) as judged by the PSO on watch.

Following a power down for the presence of a marine mammal within the full array safety radius, airgun activity will not resume until the animal has cleared the safety zone. The animal will be considered to have cleared the safety as described above in the section *Pre-Startup Observations*. If the animal is observed outside the safety zone within 20 minutes of the power down, the full array may be activated without a ramp-up. If more than 20 minutes has passed since the array was powered down, then the ramp-up procedure will be followed.

Shut-down Procedures

All operating airguns will be shut down if a marine mammal or sea turtle is seen within or approaching 150 m of the power-down source, a single airgun of 40 in^3. Airgun activity will not resume until the marine mammal or turtle has cleared the safety zone of the full array, as described in the section *Pre-Startup Observations*. If the shutdown lasts for more than 20 minutes, a 30-minute pre-startup watch must be completed prior to a ramp-up of the airgun array.

Passive Acoustic Monitoring

Use of a towed passive acoustic monitoring system will allow the airgun array to begin operating during darkness or poor visibility conditions when visual observations of the full safety zone are not possible. If marine mammals are detected within the exclusion zone during ramp up or full-array operations, a power-down or shutdown will be requeseted in the same manner as for visual observations of animals in the exclusion zone.

Chase Vessel

When not performing necessary support functions near the source vessel (e.g., protecting the streamer from damage or returning to port for fuel or any necessary personnel transfers), the chase vessel will be ~5 km in front of the source vessel. It will be there to request that any vessels on the seismic line make way and to advise the source vessel of any slight course changes to avoid fixed fishing gear. Bridge crew on the chase vessel will be instructed to alert PSOs on the source vessel of any marine mammal or sea turtle sightings.

This will increase the likelihood of PSOs aboard the source vessel detecting animals near the operation and implementing any necessary mitigation measures.

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.

Not applicable. The proposed activity will take place off the U.S. east coast and no activities will take place in or near a traditional Arctic subsistence hunting area. There are no relevant subsistence uses of marine mammals implicated by this action.

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...

ION proposes to sponsor third-party Protected Species Observers (PSOs) to conduct observations and impliment mitigation measures that require real-time monitoring. 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. ION 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 useful.

Vessel-based Visual Monitoring

During the survey, three PSOs will be based aboard the source vessel to monitor for marine mammals. Documentation of experience and successful completeion of required trainings will be provided to NMFS and BOEM for prior approval. At least one PSO will watch for marine mammals and sea turtles near the seismic vessel at least 30 minutes prior to and during ongoing daytime operations. PSOs will be on duty for no longer than 4 consecutive hours and 12 total hours within a 24 hour period. The vessel crew will also be instructed to assist in detecting marine mammals and sea turtles and implementing mitigation requirements.

Observations will be made from either the bridge or the flying bridge, which on the *Discoverer*, are greater than ~12 m above sea level. During daylight periods with good visibility, the PSO(s) will scan the area around the vessel systematically with 7×50 reticle binoculars and the unaided eye. When visibility conditions are severly reduced during daylight periods by fog, rain, etc. and make visual monitoring ineffective, PSOs will not be required to be on watch; however, as soon as conditions improve, visual observations will resume. During periods of darkness, night vision devices will be available to assist observations, if/when observations

at night are required. When feasible, observations will also be made during daytime periods when the vessel is underway without seismic operations, such as during transits.

PSO Data and Documentation

PSOs will record monitoring effort and animal detections during all watch periods. These data will be used to estimate the numbers of marine mammals exposed to various received sound levels, to document any apparent disturbance reactions or lack thereof, and thus to estimate the numbers of mammals potentially "taken" by harassment. Observers will also record the request and implementation of all mitigation measures described in §XI.

Information to be recorded by PSOs will include the same types of information that were recorded during previous monitoring projects conducted under NMFS IHAs (e.g., Reiser et al. 2010, 2011; Bisson et al. 2013; Beland et al. 2013). When a marine mammal sighting is made, the following information about the sighting will be carefully and accurately recorded:

- species, group size, age/size/sex categories (if determinable);
- behavior when first sighted and after initial sighting;
- heading (if consistent), bearing and distance from observer;
- apparent reaction to activities (e.g., none, avoidance, approach, paralleling, etc.), closest point of approach, and behavioral pace;
- time, location, speed, and activity of the vessel, sea state, ice cover, visibility, and sun glare; and
- positions of other vessel(s) in the vicinity of the observer location.

The vessel's position and speed, water depth, sea state, visibility, and sun glare will also be recorded at the start and end of each observation watch, every 30 minutes during a watch, and whenever there is a change in any of those variables that materially effects sighting conditions.

PSO's will be instructed to identify animals as unknown when appropriate rather than strive to identify an animal when there is significant uncertainty. We also ask that they provide any sightings cues they used and any distinguishable features of the animal even if they are not able to identify the animal and record it as unidentified. Emphasis is also placed on recording what was not seen, such as dorsal features.

An electronic database will be used to record and collate data obtained from visual observations during the vessel-based study. The PSOs will enter the data into the custom data entry program installed on field laptops. The data entry program automates the data entry process and reduces data entry errors while maximizing PSO time spent looking at the water.

The accuracy of the data entry will be verified by computerized data validity checks as the data are entered and by subsequent manual checking of the database. These procedures will allow initial summaries of data to be prepared during and shortly after the field program, and will facilitate transfer of the data to statistical, graphical, and other programs for further processing and archiving.

Results from the vessel-based observations will provide:

- The basis for real-time mitigation (airgun power down or shut down).
- Information needed to estimate the number of marine mammals potentially taken by harassment, which must be reported to NMFS.

- Data on the occurrence, distribution, and activities of marine mammals and sea turtles in the area where the seismic study is conducted.
- Information to compare the distance and distribution of marine mammals and sea turtles relative to the source vessel at times with and without seismic activity.
- Data on the behavior and movement patterns of marine mammals and sea turtles seen at times with and without seismic activity.

Passive Acoustic Monitoring

As described in BOEM (2014a), passive acoustic monitoring (PAM) has the capability to detect marine mammals at night and during reduced visibility. Towed PAM systems have become an increasingly common tool for mitigation monitoring during seismic surveys and the latest hardware and software combinations provide automated detection, classification, and localization of strong signals. Although these systems typically increase the number of marine mammal detections recorded by observers, they require that marine mammals be actively calling or echolocating within the detection range of the system in order to be detected. Detection ranges can vary substantial as a result of masking from vessel noise, flow noise, seismic source noise and reverberation, and high sea states. An appropriate PAM system and qualified operators will be selected prior to the survey. A description of the passive acoustic system, the software to be used, and the monitoring protocol will be developed and provided to NMFS during the application review process.

Reporting

Daily or weekly reports will be submitted to NMFS and other federal agencies as required by permit/authorization stipulations. A summary report will be submitted to NMFS within 90 days after the end of the cruise. The report will describe the operations that were conducted and sightings of marine mammals and turtles near the operations. The report will provide full documentation of methods, results, and interpretation pertaining to all monitoring activities and mitigation actions. The 90-day report will summarize the dates and locations of seismic operations, and all marine mammal and turtle sightings (dates, times, locations, activities, associated seismic survey activities). The report will also include estimates of the amount and nature of potential "take" 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.

ION will coordinate the planned marine mammal monitoring program associated with the seismic survey off the U.S. east coast (as summarized in § XI and XIII) with other parties that may have interest in the area and/or be conducting marine mammal studies in the same region during the proposed seismic survey. At this time, no such entities have been identified.

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APPENDIX A: MODELING UNDERWATER SOUND FROM A 6420 IN^3 AIRGUN ARRAY

Modeling Underwater Sound from a 6420 in^3 Airgun Array

Mid- and South Atlantic Coast, USA

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Contents

1. INTRODUCTION 1

2. ACOUSTIC METRICS 2

3. MODELING LOCATIONS AND SCENARIOS 4

4. MODELING METHODS 6

4.1. Airgun Array Source Levels 6

4.2. Sound Propagation Models 8

4.3. Acoustic Environment 10

4.3.1. Bathymetry 10

4.3.2. Water sound speed profile 11

4.3.3. Geoacoustics 12

4.4. SEL to 90% rms SPL Conversion 15

4.5. M-weighting 16

5. RESULTS 18

5.1. SEL Per-pulse Modeling Results 18

5.2. rms SPL Modeling Results 27

6. DISCUSSION AND CONCLUSION 31

GLOSSARY 34

LITERATURE CITED 37

APPENDIX A. SOUND SPEED PROFILES FOR MODELED SITES A-1

APPENDIX B. RMS SPL CONTOUR MAPS FOR MODELED SITES B-1

Figures

Figure 1. Example waveform of an impulsive noise measurement. 3
Figure 2. Map of survey area showing 18 modeled locations on survey lines 1 to 6. 4
Figure 3. Geometry layout of 6420 in^3 airgun array. 6
Figure 4. Overpressure signature and power spectrum for the 6420 in^3 airgun array in the broadside and forward endfire directions. 7
Figure 5. Azimuthal directivity pattern of source level (dB re 1 μPa^2·s @ 1 m) for the 6420 in^3 airgun array. 8
Figure 6. Plot of the bathymetry grid used for acoustic modeling. UTM zone is 18N. 10
Figure 7. Representative temperature, salinity, sound speed plots for the acoustic calculation area surrounding modeled site 6 (July–December). 11
Figure 8. Sound speed plots for the acoustic calculation area surrounding modeled site 6 (July–December) for the top 200 m water depth. 12
Figure 9. Distribution of surficial sediment types in the modeled area 14
Figure 10. Range-dependent offsets between rms SPL and SEL for bottom depths (zb) of 40 m, 150 m, and 1000 m 16
Figure 11. Standard M-weighting functions for low-, mid-, and high-frequency cetaceans, and for pinnipeds in water. 17
Figure 12. Contours of unweighted (flat-weighted) and M-weighted SEL per pulse (dB re 1 μPa^2·s) produced by the 6420 in^3 airgun array in August at site 8. 19
Figure 13. Contours of unweighted (flat-weighted) and M-weighted SEL per pulse (dB re 1 μPa^2·s) produced by the 6420 in^3 airgun array in December at site 8. 20
Figure 14. Unweighted SEL per pulse (dB re 1 μPa^2·s) as a function of range and depth for one transect (broadside: 36° clockwise from UTM North) from site 8. 20
Figure 15. Contours of unweighted (flat-weighted) and M-weighted SEL per pulse (dB re 1 μPa^2·s) produced by the 6420 in^3 airgun array in August at site 9. 21
Figure 16. Contours of unweighted (flat-weighted) and M-weighted SEL per pulse (dB re 1 μPa^2·s) produced by the 6420 in^3 airgun array in December at site 9. 22
Figure 17. SEL per pulse (dB re 1 μPa^2·s) as a function of range and depth for one transect (broadside: 36° clockwise from UTM North) from site 9. 22
Figure 18. Contours of unweighted (flat-weighted) and M-weighted SEL per pulse (dB re 1 μPa^2·s) produced by the 6420 in^3 airgun array in August at site 10. 23
Figure 19. Contours of unweighted (flat-weighted) and M-weighted SEL per pulse (dB re 1 μPa^2·s) produced by the 6420 in^3 airgun array in December at site 10. 24
Figure 20. SEL per pulse (dB re 1 μPa^2·s) as a function of range and depth for one transect (broadside: 36° clockwise from UTM North) at site 10. 24
Figure 21. Contours of rms SPL (dB re 1 μPa) produced by the 6420 in^3 airgun array at sites 8−11; 28
Figure 22. Predicted 1/3-octave-band unweighted SEL per pulse (dB re 1 μPa^2·s) as a function of range for December at site 8 (water depth of 30 m). 31
Figure 23. Predicted 1/3-octave-band unweighted SEL per pulse (dB re 1 μPa^2·s) as a function of range for December at site 9 (water depth of 700 m). 32

Tables

Table 1. Modeled source locations in longitude/latitude and Universal Transverse Mercator (UTM) coordinates. UTM zone is 18N. Tow direction is clockwise from UTM north. 5
Table 2. Modeled seabed geoacoustic properties for Site 8 in August. Sediment type is sand. The water sound speed for August at sea bottom is 1534.6 m/s. mbsf is meters below seafloor. 14
Table 3. Modeled seabed geoacoustic properties for Site 7 in August and December. 15
Table 4. Low- and high-frequency cut-off parameters of M-weighting curves for each marine mammal functional hearing group proposed by Southall et al. (2007). 18
Table 5. Summary of predicted radii of unweighted (Flat-weighted) and M-weighted SEL per pulse for modeled sites on survey line 1. 25
Table 6. Summary of predicted radii of unweighted (Flat-weighted) and M-weighted SEL per pulse for modeled sites on survey line 2. 25
Table 7. Summary of predicted radii of unweighted (Flat-weighted) and M-weighted SEL per pulse for modeled sites on survey line 3. 26
Table 8. Summary of predicted radii of unweighted (Flat-weighted) and M-weighted SEL per pulse for modeled sites on survey line 4. 26
Table 9. Summary of predicted radii of unweighted (Flat-weighted) and M-weighted SEL per pulse for modeled sites on survey line 5. 27
Table 10. Summary of predicted radii of unweighted (Flat-weighted) and M-weighted SEL per pulse for modeled sites on survey line 6. 27
Table 11. Summary of predicted SPL radii for modeled sites 1–3 on survey line 1. 29
Table 12. Summary of predicted SPL radii for modeled sites 4–7 on survey line 2. 29
Table 13. Summary of predicted SPL radii for modeled sites 8–11 on survey line 3. 29
Table 14. Summary of predicted SPL radii for modeled sites 12–14 on survey line 4. 30
Table 15. Summary of predicted SPL radii for modeled sites 15–16 on survey line 5. 30
Table 16. Summary of predicted SPL radii for modeled sites 17–18 on survey line 6. 30
Table 17: Summary of predicted SPL radii ($R_{95\%}$) for modeled sites 1–18. 33

1. Introduction

This report estimates expected sound levels originating from a seismic exploration program proposed to occur off the eastern coast of the United States. The seismic source is a 36-element airgun array with a 6420 in^3 total firing volume; it will operate from July to December. The survey area in which the array will be operated includes both shelf and offshore regions from New Jersey to Florida.

The goal of this study is to estimate ranges from the array within which sound levels would exceed recommended thresholds for marine mammals. Eighteen representative sites along proposed survey lines were modeled to calculate sound level distributions at geographically distinct areas of the survey region. The acoustic signature of the airgun array was predicted with an Airgun Array Source Model (AASM) developed by JASCO Applied Sciences Ltd. (JASCO). A complementary acoustic propagation model, JASCO's Marine Operations Noise Model (MONM), was used to calculate the sound propagation and acoustic field near each defined site. MONM accepts ocean bathymetry, water sound speed profiles, and seabed geoacoustics as inputs. The results of the sound level calculations are presented in two formats: 1) Sound field contour maps, which show the planar distribution of sound levels with range and direction around the airgun array, and 2) Tables that list maximum-over-depth distances from the array to impact threshold sound levels.

To help readers interpret the results, Section 2 includes definitions of the acoustic metrics and terminology used in this report. Section 3 describes the 18 modeled sites. Section 4 explains the modeling methods—the airgun source model, the sound propagation model, the environmental parameters input to the acoustic models, the approach to convert SEL to rms SPL, and M-weighting. Section 5 contains results, which are then discussed and summarized in Section 6.

2. Acoustic Metrics

Underwater sound amplitude is commonly measured in decibels (dB), which is a logarithmic scale that expresses a quantity relative to a predefined reference level. Sound pressure, in dB, is expressed in terms of the sound pressure level (SPL), symbolized L_p:

$$L_p = 20\log_{10}(P / P_{ref}) \tag{1}$$

where P is the pressure amplitude and P_{ref} is the reference sound pressure. For underwater sound, 1 µPa (10^{-6} Pa or 10^{-11} bar) is the generally accepted reference pressure.

Impulsive sounds are very short in duration (less than a few seconds). These are typically characterized by abrupt increases of sound pressure lasting less than a second, rapidly decaying back to pre-existing levels (within a few seconds). Noise from airguns is generally considered impulsive. The zero-to-peak, or peak SPL (L_{pk}, dB re 1 µPa) is the maximum instantaneous sound pressure level attained by an impulse, $p(t)$:

$$L_{pk} = 20\log_{10}\left(\max\left|p(t)\right| / P_{ref}\right) \tag{2}$$

In this formula, $p(t)$ is the instantaneous sound pressure as a function of time, measured over the impulse duration $0 \le t \le T$. This metric is commonly quoted for impulsive sounds, but it does not consider the duration or bandwidth of the noise. At high intensities the peak SPL can be a valid criterion to assess whether a sound is potentially injurious; however, because the peak SPL does not consider pulse duration, it is not a good indicator of perceived loudness. A similar metric, the peak-to-peak SPL ($L_{pk\text{-}pk}$) measures the difference between the maximum and minimum instantaneous sound pressure levels.

The root-mean-square (rms) SPL (L_p, dB re 1 µPa) is measured over the impulse duration according to the following equation:

$$L_p = 10\log_{10}\left(\frac{1}{T}\int_T p(t)^2\,dt / P_{ref}^2\right) \tag{3}$$

Some ambiguity remains in how the duration T is defined because in practice the beginning and end of an impulse can be difficult to identify precisely. In studies of impulsive noise, T is often accepted as the interval over which the cumulative energy curve rises from 5% to 95% of the total energy. This interval contains 90% of the total pulse energy (T_{90}); the SPL computed over this interval is commonly referred to as the 90% rms SPL (L_{p90}). The relative energy, $E(t)$, of the impulse is computed from the time integral of the square pressure:

$$E(t) = \int_0^t p(\tau)^2\,d\tau / P_{ref}^2 \tag{4}$$

According to this definition, if the time corresponding to n% of the total relative energy of the impulse is denoted t_n, then the 90% energy window is defined such that $T_{90} = t_{95}\text{–}t_5$. Figure 1 shows an example of an impulsive noise pressure waveform, with the corresponding peak pressure, rms pressure, and 90% energy time interval.

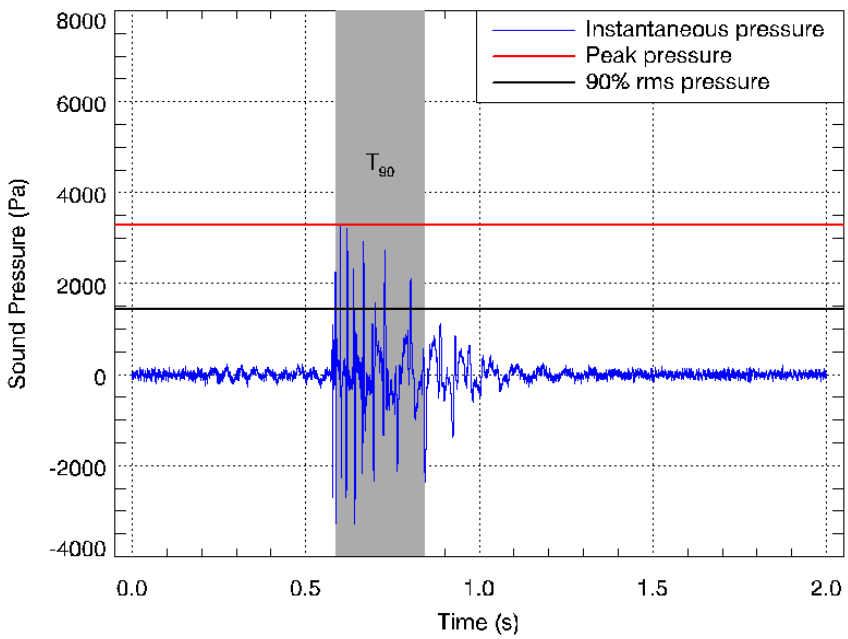


Figure 1. Example waveform of an impulsive noise measurement. Horizontal lines indicate the peak pressure and 90% rms pressure for this impulse. The grey area indicates the 90% energy time window (T_{90}) over which the rms pressure is computed.

The sound exposure level (L_E, dB re 1 µPa^2·s) is a measure of the total sound energy contained in one or more impulses. The sound exposure level (SEL) for a single impulse is computed from the time-integral of the squared pressure over the impulse duration:

$$L_E = 10\log_{10}\left(\int_{T_{100}} p(t)^2\,dt / P_{ref}^2\right) = 10\log_{10}\left(E(T_{100})\right) \tag{5}$$

SELs for impulsive noise sources (i.e., airgun shots) presented in this report refer to single pulse SELs.

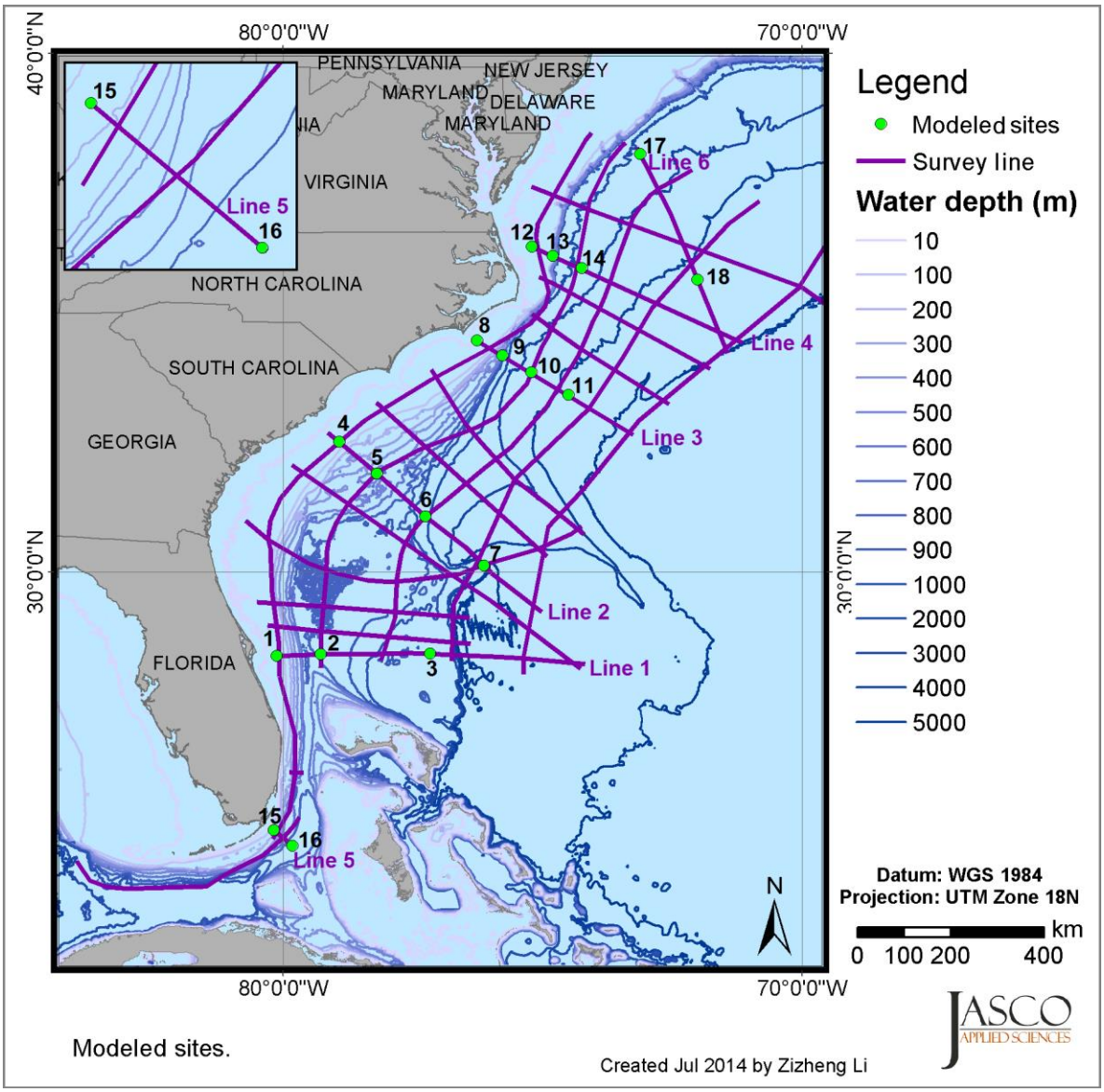
Because the 90% rms SPL and SEL for a single impulse are both computed from the integral of square pressure, these metrics are related by an expression that depends only on the duration of the 90% energy time window T_{90}:

$$L_E = L_{P90} + 10\log_{10}(T_{90}) + 0.458 \tag{6}$$

In this formula, the 0.458 dB factor accounts for the remaining 10% of the impulse energy that is excluded from the 90% time window. In the report, all references to rms levels refer to the 90% rms SPL metric.

3. Modeling Locations and Scenarios

In this study, 18 representative sites were selected at various points along six survey track lines (Figure 2 and Table 1). The modeled results will be used to conduct acoustic integration modeling to predict the potential impacts to marine mammals from the planned seismic survey. For consistency, the tow direction was assumed to be from onshore to offshore along each track line.



Modeled sites.

Figure 2. Map of survey area showing 18 modeled locations on survey lines 1 to 6.

Table 1. Modeled source locations in longitude/latitude and Universal Transverse Mercator (UTM) coordinates. UTM zone is 18N. Tow direction is clockwise from UTM north.

Site	Latitude (°N)	Longitude (°W)	UTM Easting (m)	UTM Northing (m)	Tow direction (degree)	Water Depth (m)
1	28.38309	80.1332	-3289	3150377	88	45
2	28.41155	79.2786	80712	3150256	88	820
3	28.42494	77.1715	287308	3146191	93	1000
4	32.50479	78.9226	131409	3603177	135	40
5	31.89874	78.1955	197767	3533664	135	650
6	31.06751	77.2588	284487	3439275	135	1500
7	30.12418	76.1398	390203	3333093	135	2600
8	34.46330	76.2763	382777	3814266	126	30
9	34.17096	75.7760	428481	3781389	126	700
10	33.84273	75.2238	479294	3744738	126	3300
11	33.40949	74.5035	546166	3696796	126	4200
12	36.27238	75.2167	480537	4014184	118	30
13	36.09425	74.8044	517608	3994414	118	140
14	35.85348	74.2543	567333	3967956	118	2400
15	25.03020	80.1902	-24079	2778353	133	190
16	24.72899	79.8327	10893	2743582	133	870
17	38.05702	73.1276	664272	4213794	158	2200
18	35.63709	72.0254	769357	3947774	160	4180

4. Modeling Methods

4.1. Airgun Array Source Levels

This survey has proposed a 36-element airgun array with a total firing volume of 6420 in^3. The array consists of four identical 9-element sub-arrays, with individual volumes between 40 in^3 and 380 in^3, fired simultaneously with a firing pressure of 2000 psi. The tow depth is 10 m. The array geometry is shown in Figure 3.

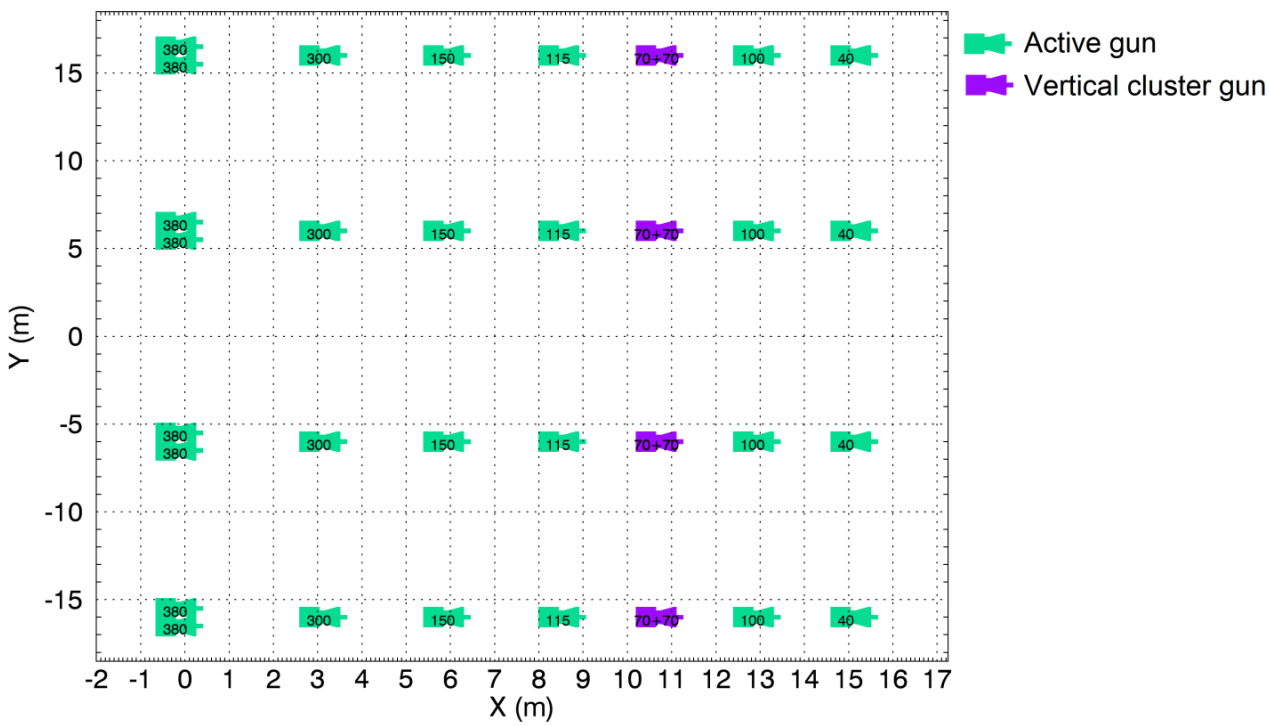


Figure 3. Geometry layout of 6420 in^3 airgun array. The pairs of 70 in^3 guns are separated by 70 cm in the z-direction (vertically). Tow depth is 10 m. Tow direction is in the –x direction.

The acoustic source levels and directivity patterns of the airgun array were predicted using JASCO's Airgun Array Source Model (AASM, MacGillivray 2006). AASM simulates the expansion and oscillation of the bubbles generated by each airgun within a seismic array and takes into account the effects of pressure interaction between bubbles from different airguns. It includes effects from surface-reflected pressure waves, heat transfer from the bubbles to the surrounding water, and the movements of bubbles due to their buoyancy. AASM produces a set of notional signatures for each array element based on the array layout as well as the volume, tow depth, and firing pressure of each airgun. These notional signatures are the pressure waveforms of the individual airguns at a standard reference distance of 1 m; they account for the interactions with the other airguns in the array. These signatures are superimposed with the appropriate time delays to yield the overall array source signature in any direction. This far-field array signature is filtered into 1/3-octave passbands to compute the source levels of the array as a function of frequency band and azimuthal angle in the horizontal plane. The interactions between

individual elements of the array create directionality in the overall acoustic emission. Generally, this directionality is prominent mainly at frequencies in the mid-range of several tens to several hundred hertz; at lower frequencies, with acoustic wavelengths much larger than the inter-airgun separation distances, directivity is small. At higher frequencies, the pattern of lobes becomes too finely spaced to be resolved and the effective directivity is reduced.

Figure 4 shows the overpressure signatures and the power spectra for the broadside (perpendicular to tow) and forward endfire (parallel to tow) directions. Spectral levels generally decrease with increasing frequency, and most of the airgun array energy was below 200 Hz.

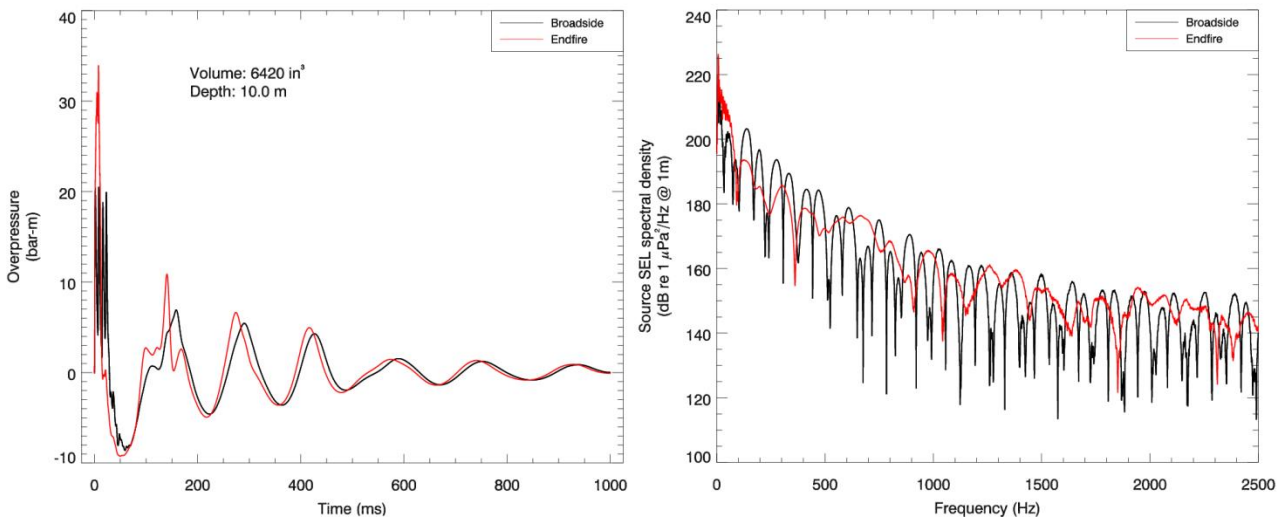


Figure 4. Overpressure signature and power spectrum for the 6420 in^3 airgun array in the broadside and forward endfire directions.

Figure 5 shows the horizontal directivity of the array as a function of frequency. Source directivity is insignificant at 50 Hz or less, but is quite prominent for higher frequencies.

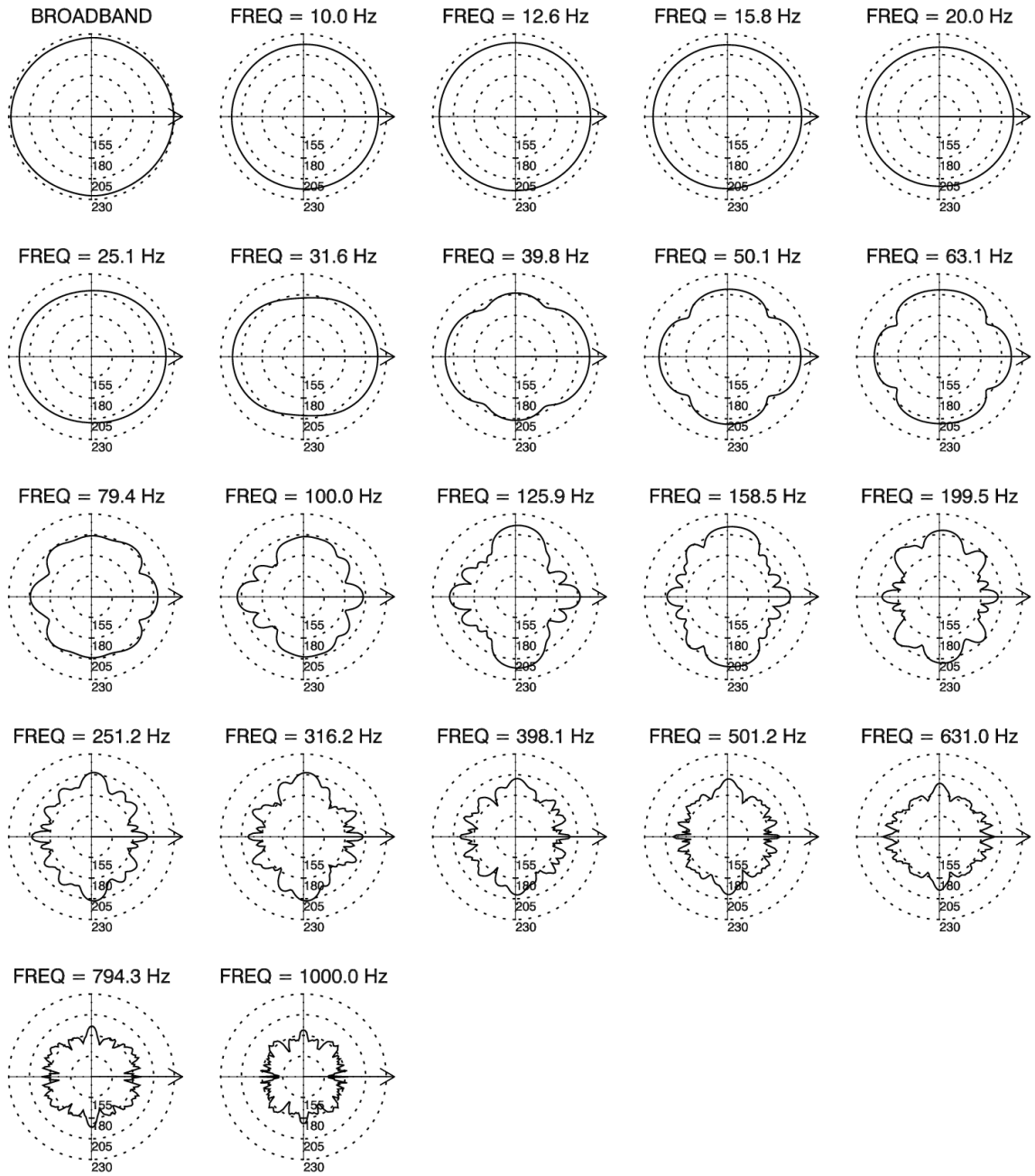


Figure 5. Azimuthal directivity pattern of source level (dB re 1 μPa^2·s @ 1 m) for the 6420 in^3 airgun array. Plots are shown for the broadband source level and for 1/3-octave bands with center frequencies from 10 Hz to 1 kHz. Arrows indicate the array tow axis direction.

4.2. Sound Propagation Models

In this study, underwater sound propagation was predicted with JASCO's Marine Operations Noise Model (MONM). MONM computes sound propagation in range-varying acoustic environments through a wide-angled parabolic equation (PE) solution to the acoustic wave equation (Collins 1993). The PE method has been extensively benchmarked and is widely employed in the underwater acoustic community (Collins et al. 1996). The PE code used by

MONM is based on a version of the Naval Research Laboratory's Range-dependent Acoustic Model (RAM), which has been modified to account for an elastic seabed (Zhang and Tindle 1995).

MONM computes acoustic fields in three dimensions by modeling transmission loss along evenly spaced 2-D radial traverses covering a 360° swath from the source, an approach commonly referred to as N × 2-D. The model fully accounts for depth and/or range dependence of several environmental parameters including bathymetry and sound speed profiles for the water column and the sea floor. It also accounts for the additional reflection loss at the seabed that is due to partial conversion of incident compressional waves to shear waves at the seabed and sub-bottom interfaces through a complex density approximation (Zhang and Tindle 1995). It includes wave attenuations in all layers. The acoustic environment is sampled at a fixed range step along radial traverses. MONM treats frequency dependence by computing acoustic transmission loss (TL) at the center frequencies of 1/3-octave bands. Broadband received levels are summed over the received 1/3-octave-band levels, which are computed by subtracting band TL values from the corresponding source levels. MONM's predictions have been validated against experimental data from several underwater acoustic measurement programs (Hannay and Racca 2005, Aerts et al. 2008, Funk et al. 2008, Ireland et al. 2009, O'Neill et al. 2010, Warner et al. 2010).

MONM calculates transmission loss to receiver locations at various distances, depths, and bearings from an equivalent point-like acoustic source. A seismic array, however, consists of many distributed sources. The point-source assumption is not valid in the near-field where the array elements do not add coherently. The maximum extent of the near-field of an array (R_{nf}) is:

$$R_{nf} < \frac{L^2}{4\lambda} \tag{7}$$

where λ is the sound wavelength and L is the longest dimension of the array (Lurton 2002). For the airgun array described in Section 4.1, L ≈ 36 m (along the diagonal of the array) and the maximum extent of the near-field is 216 m at 1 kHz and 22 m at 100 Hz (water sound speed was assumed to be 1500 m/s). Beyond the frequency-specific ranges an array is assumed to radiate like a directional point source and is treated as such for propagation modeling with MONM.

In this study, we computed acoustic transmission loss at the center frequencies of 1/3-octave bands between 10 Hz and 1 kHz. This frequency range includes the important bandwidth of noise emissions from the airgun array systems. For the PE model horizontal computational grid, we used a 10 m radial step size. Sound levels were modeled at 100 different receiver depths, distributed vertically in the water column from 2 m to a maximum of 2000 m, generated from the following equation:

$$z = 2n^{1.5} \tag{8}$$

where z is the receiver depth in meters and n is an integer index that n = 1, 2, 3,…,100. The receiver depths have greater resolution near the surface. The upper limit of 2000 m was chosen because marine mammals do not normally dive to depths > 2000 m and received levels at deeper depths are not directly relevant here.

Modeled received levels were gridded separately in each horizontal plane (i.e., at each modeled receiver depth). As a conservative estimate, the modeled results in this study were obtained by collapsing the stack of grids into a single plane using a maximum-over-depth rule, which means

that the sound levels at each planar point are taken to be the maximum value from all modeled depths in the water column for that point.

In this report, the 95th percentile radius, $R_{95\%}$, and the maximum radius, R_{max}, for each noise threshold level were tabulated. The $R_{95\%}$ is the radius of a circle that encompasses 95% of the grid points whose value is equal to or greater than the threshold value. For a given threshold level, this radius always provides a range beyond which no more than 5% of a uniformly distributed population would be exposed to sound at or above that level, regardless of the geometrical shape of the noise footprint. The R_{max} is the maximum distance from the source to the given noise threshold in any direction (equivalent to $R_{100\%}$). R_{max} can be a reference for the most conservative case compared to using $R_{95\%}$. For cases where the ensonification to a specific level is discontinuous and small pockets of higher received levels occur far beyond the main ensonified volume (e.g., due to convergence of sound rays), R_{max} would be much larger than $R_{95\%}$ and could therefore be misleading if not given alongside $R_{95\%}$.

4.3. Acoustic Environment

4.3.1. Bathymetry

Bathymetry data for the modeled area were obtained from SRTM30+ (Version 6.0) global bathymetry grid, a 30 arc-second grid rendered for the entire globe (Rodríguez et al. 2005). The grid is based on a combination of satellite-based synthetic aperture radar altimetry and vessel-based bathymetric measurements. The data were converted to a format accepted by JASCO's MONM in UTM zone 18N coordinates with a regular grid spacing of 200 × 200 m resolution (Figure 6).

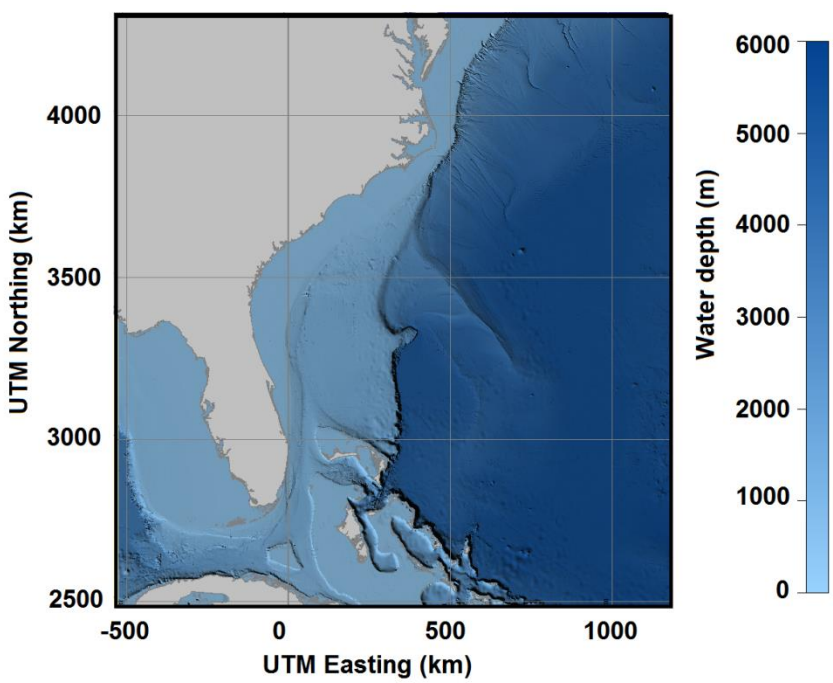


Figure 6. Plot of the bathymetry grid used for acoustic modeling. UTM zone is 18N.

4.3.2. Water sound speed profile

For each modeled site, the water column sound speed profile (SSP) was computed from temperature and salinity data from the U.S. Naval Oceanographic Office's Generalized Digital Environmental Model (GDEM) database version 3.0 (Carnes 2009). The GDEM database provides average monthly profiles of temperature and salinity for the world's oceans on a latitude/longitude grid with a 0.25° resolution. The profiles in GDEM are based on historical observations of global temperature and salinity from the U.S. Navy's Master Oceanographic Observational Data Set (MOODS). The climatology profiles include 78 fixed depth points to a maximum depth of 6800 m, including 55 standard depths between 0 and 2000 m. The SSPs were derived from the GDEM temperature and salinity profiles according to the following formulae (Clay and Medwin 1977):

$$\begin{aligned} c(z,T,S) &= 1449.2 + 4.6T - 0.055T^2 + 0.00029T^3 \\ &\quad + (1.34 - 0.01T)(S - 35) + 0.016z \end{aligned} \tag{9}$$

where z is depth (m), T is water temperature (°C), and S is salinity (psu). The sound speed profiles vary by season because water temperature and salinity change seasonally. Figure 7 shows representative July to December temperature, salinity, and sound speed for the acoustic calculation area surrounding modeled site 6. Figure 8 shows the corresponding sound speed profiles for the top 200 m water depth.

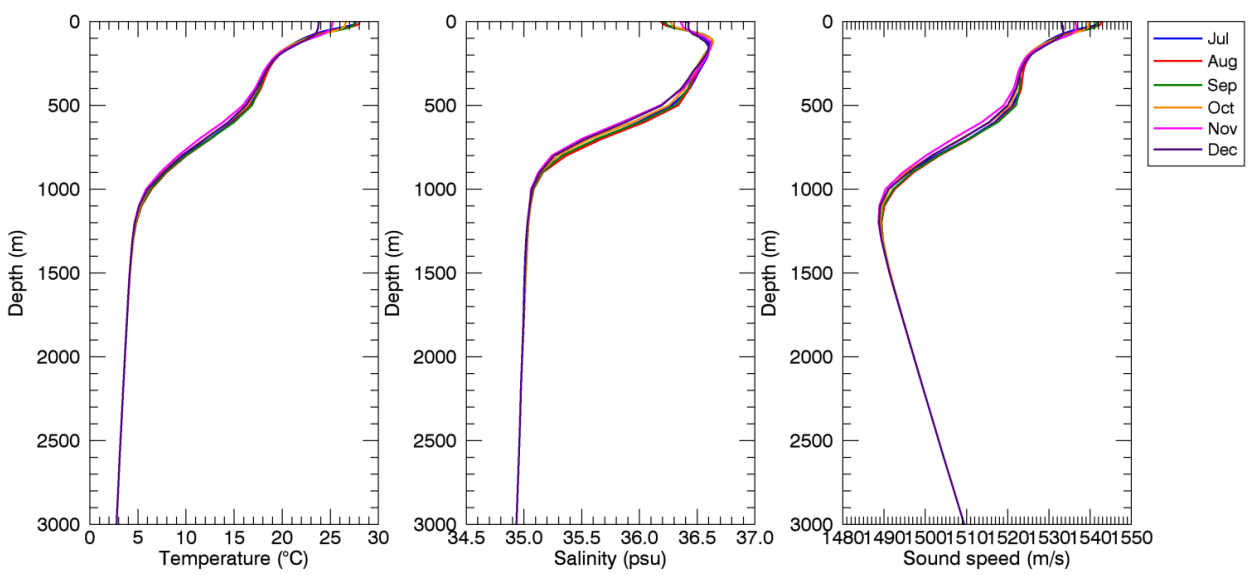


Figure 7. Representative temperature, salinity, sound speed plots for the acoustic calculation area surrounding modeled site 6 (July–December).

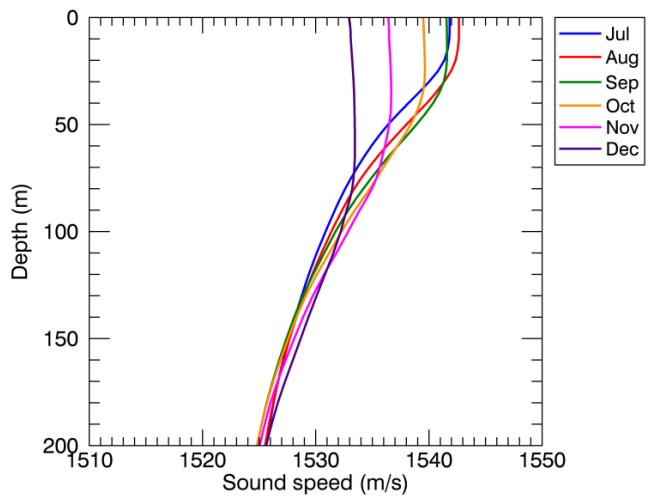


Figure 8. Sound speed plots for the acoustic calculation area surrounding modeled site 6 (July–December) for the top 200 m water depth.

We selected two sets of sound speed profiles, August and December, to present the worst and best propagation scenarios, respectively. Each monthly profile has a strongly downward-refracting portion, which would cause sound energy to be directed into the bottom, resulting in more energy lost to seabed sediments (bottom loss). Although this is also true of the December SSP, in December the surface layer is deeper than in other months and has a slightly positive sound speed gradient (i.e., temperature increasing with depth) near the surface so the surface layer traps more sound in the channel, where it better supports long-range propagation by minimizing bottom loss. In contrast, the August SSP has the shallowest mixed layer and a generally negative sound speed gradient, allowing more sound to travel away from the near-surface region and eventually into the sediments.

In this study, since the acoustic field extended up to 50 km away from the modeled sites, where SSPs can extend to greater depths than the sites' water depths, the SSPs were selected from the receiver locations with the deepest water. Appendix A lists the representative August and December sound speed profiles for other modeled sites.

4.3.3. Geoacoustics

Underwater sound propagation in shallow water is strongly influenced by the geoacoustic properties of the sea floor. These include density (ρ), compressional wave speed (v_p), shear wave speed (v_s), and attenuation properties (α_p and α_s) of seabed sediments. MONM incorporates all of these parameters when calculating transmission loss. Surficial sediment-type data were available from the USGS Continental Margin Program (Hathaway 1977) and the NGDC Seafloor Sediment Descriptions (Bershad and Weiss 1975). Poppe et al. (2005) presented a map of the surficial sediment distribution for the region (Figure 9). According to the map, sand or clay comprise over 85% of the surficial sediments in the modeled area; the remaining 15% is characterized by transitional sediment types.

In this study, the 18 modeled sites covered a range of bottom type environments. A more generic approach to define geoacoustic parameters was used to allow the modeled sites to be representative over larger portions of the overall survey area. We considered both the sediment

type found at the sea bottom and averaged sub-bottom porosity profiles. Sites 1–5, 8, 9, 12, 13, and 15 are located on sand sediments. The geoacoustic profiles for sand sediments were constructed based on data obtained by the Ocean Drilling Program (ODP) at site 1071, Leg 174 (Shipboard Scientific Shipboard Scientific Party 1998). The reported porosity for the surficial sediments was 50%, which decreased gradually to 40% at 150 m below the seafloor, and remained constant for greater depths. Sites 6, 7, 10, 11, 14, and 16–18 are located on clay sediments. The geoacoustic profiles for clay sediments were constructed based on the data obtained by ODP at site 995, Leg 164 (Shipboard Scientific Shipboard Scientific Party 1996). The reported porosity for the surficial sediments was 80% and decreased to 48% at depths of 700 m below the sea floor. Geoacoustic parameters were then computed based on Buckingham's (2005) grain-shearing model, which computes geoacoustic properties of seabed sediment (sand, silt, clay) from porosity and grain size.

Tables 2 through 3 present modeled geoacoustic parameters for two of the modeled sites, representing the sand and clay sediment types, respectively. Note that the geoacoustic properties vary slightly among modeled sites due to difference in the water sound speeds at the sea bottom.

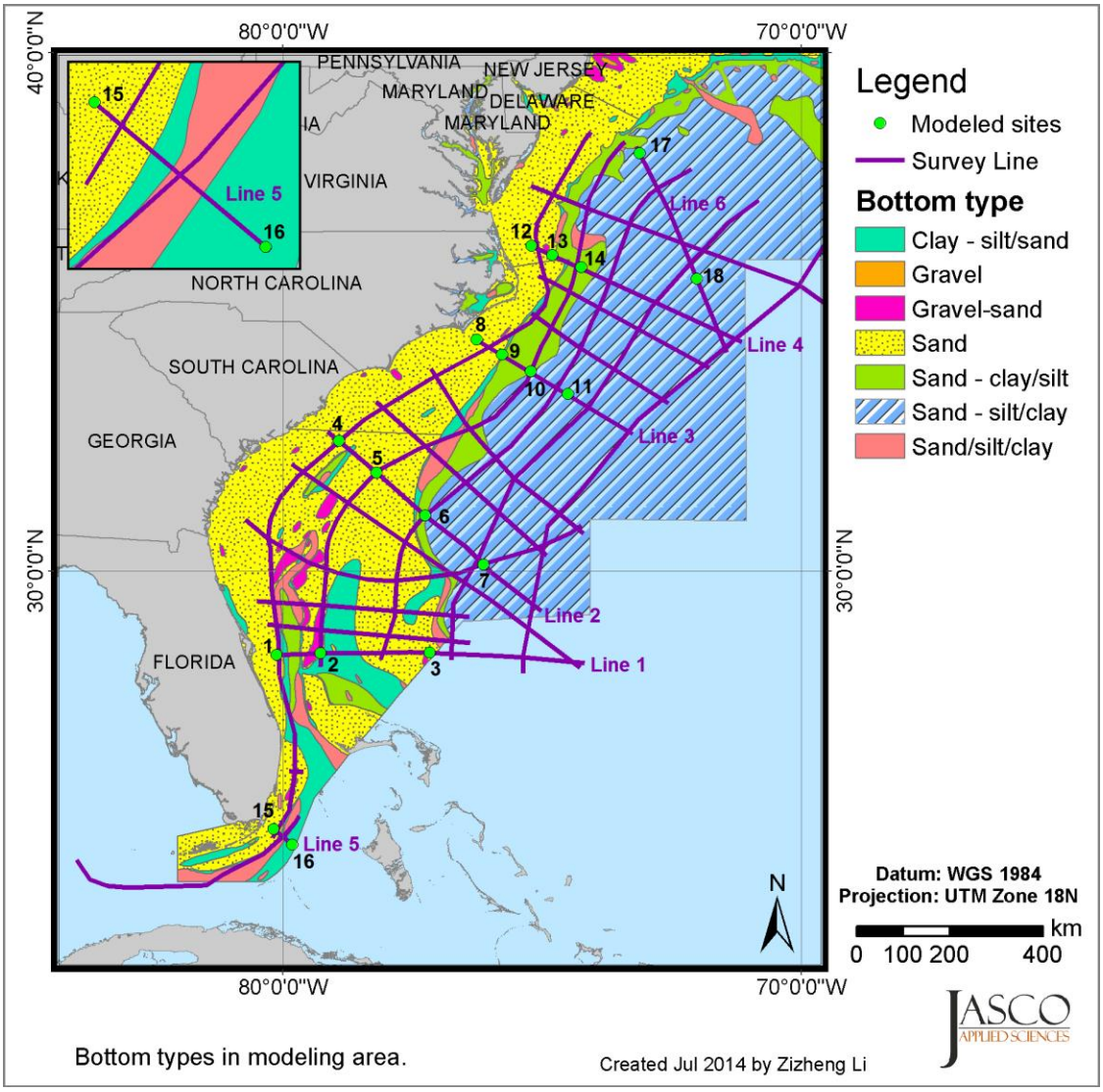


Figure 9. Distribution of surficial sediment types in the modeled area (adapted from Poppe et al. 2005).

Table 2. Modeled seabed geoacoustic properties for Site 8 in August. Sediment type is sand. The water sound speed for August at sea bottom is 1534.6 m/s. mbsf is meters below seafloor.

Depth (mbsf)	Density (g/cm^3)	P-wave speed (m/s)	P-wave attenuation (dB/λ)	S-wave speed (m/s)	S-wave attenuation (dB/λ)
0–10	1.87	1634–1755	0.40–0.83	547	3.58
10–20	1.87	1755–1819	0.83–1.03		
20–50	1.87	1819–1950	1.03–1.31		
50–100	1.92–1.99	1950–2095	1.31–1.53		
100–200	1.99–2.04	2095–2273	1.53–1.79		
200–500	2.04	2273–2563	1.79–2.18		
> 500	2.04	2563	2.18		

Table 3. Modeled seabed geoacoustic properties for Site 7 in August and December. Sediment type is clay. The averaged water sound speed for August and December at sea bottom is 1532.8 m/s. mbsf is meters below seafloor.

Depth (mbsf)	Density (g/cm^3)	P-wave speed (m/s)	P-wave attenuation (dB/λ)	S-wave speed (m/s)	S-wave attenuation (dB/λ)
0–10	1.35–1.36	1491–1521	0.12–0.26	136	0.31
10–20	1.36–1.37	1521–1536	0.26–0.33		
20–50	1.37–1.39	1536–1566	0.33–0.46		
50–100	1.39–1.43	1566–1604	0.46–0.61		
100–200	1.43–1.51	1604–1670	0.61–0.84		
200–500	1.51–1.75	1670–1906	0.84–1.38		
> 500	1.75	1906	1.38		

4.4. SEL to 90% rms SPL Conversion

Existing U.S. safety radius regulations for impulsive sound sources are based on the rms SPL metric. The 90% rms SPL can be obtained from its relationship with SEL, which depends on T_{90}, as described in Equation 6. The pulse duration T_{90} is generally unknown and sensitive to the specific multipath arrival pattern, which can vary greatly with distance from the source or with receiver depth.

There are two approaches that can determine the integration time, T_{90}:

1) Use empirical values based on field measurements made in similar environments, or

2) Use a full-waveform acoustic model to predict the range-dependent pressure waveform from which the relationship between the SEL and 90% rms SPL can be extracted directly.

In various empirical studies where the rms SPL, SEL, and duration have been measured for individual airgun pulses, the difference between the rms SPL and the SEL is typically 5–15 dB and varies considerably with the water depth and the geoacoustic environment (Greene 1997, McCauley et al. 1998, Blackwell et al. 2007, MacGillivray et al. 2007). Generally, the measured offset between the rms SPL and the SEL is larger at closer distances, where the pulse duration is short ($\ll$ 1 s), and smaller at farther distances, where pulse duration tends to increase because of propagation effects.

The first approach estimates the approximate radii since the true time over which the pulse spreads has not actually been modeled. The second approach considers the accurate pulse length information in the full-wave model, but it is not computationally practical to run the full-waveform model for each radial transect modeled by MONM. In this case, the conversion factors are still approximate, as are the safety radii obtained.

For this study, the SEL to 90% rms SPL conversion curves were adapted from a previous modeling study carried out in this area (Gaboury et al. 2008). In the 2008 study, full-waveform modeling was applied to examine the absolute near-field rms SPL–SEL offsets and their general variation with range. Full-waveform results were obtained for idealized flat bottom models with water depths of 40 m, 150 m, and 1000 m. The bottom types were sand for the 40 m and 150 m

models, and clay for the 1000 m model. The results of the full-waveform modeling were combined with data obtained during field measurements of seismic sources in similar depth regimes (Austin et al. 2003, Funk et al. 2008). The resulting rms SPL–SEL offsets as a function of distance from the source are shown in Figure 10. These offset functions were applied to the SELs computed by MONM for each of the 18 modeled sites to generate the estimated rms SPLs, based on the bottom depth at the source as follows:

- Sites with water depths less than 60 m—the rms SPL–SEL offsets for 40 m bottom depth.
- Sites with water depth from 61 to 300 m—the rms SPL–SEL offsets for 150 m bottom depth.
- Sites deeper than 300 m—the rms SPL–SEL offsets for 1000 m bottom depth.

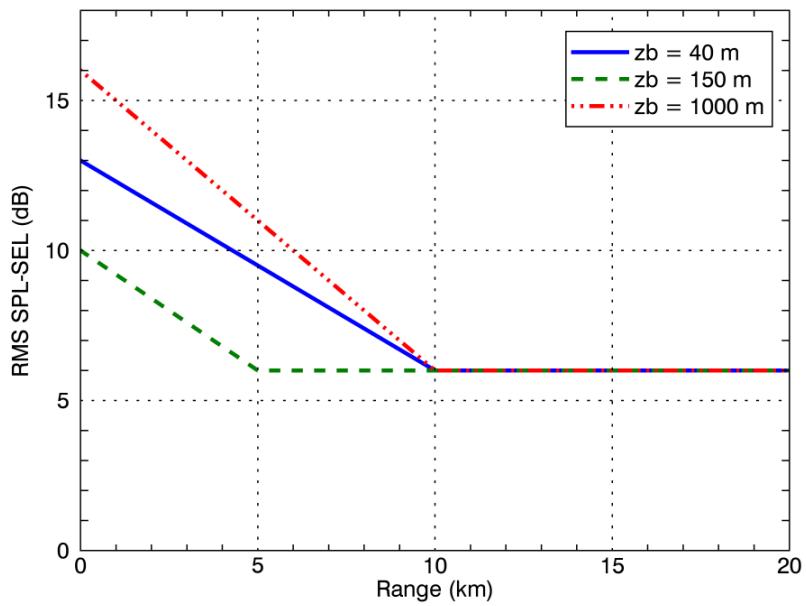


Figure 10. Range-dependent offsets between rms SPL and SEL for bottom depths (zb) of 40 m, 150 m, and 1000 m (Gaboury et al. 2008).

4.5. M-weighting

Based on a literature review of marine mammal hearing and on physiological and behavioral responses to anthropogenic sound, Southall et al. (2007) proposed standard frequency weighting functions–referred to as M-weighting functions–for five functional hearing groups of marine mammals:

- Low-frequency cetaceans (LFC)–mysticetes (baleen whales)
- Mid-frequency cetaceans (MFC)–some odontocetes (toothed whales)
- High-frequency cetaceans (HFC)–odontocetes specialized for using high-frequencies
- Pinnipeds in water (PINN)–seals, sea lions, and walrus
- Pinnipeds in air

The M-weighting approach is typically applied to evaluate potential injury and onset of temporary threshold shift (TTS) from animals being exposed to high amplitude sounds, such as

those from airgun arrays (Southall et al. 2007). The discount applied by the M-weighting functions for less-audible frequencies is less than that indicated by the corresponding audiograms (where available) for member species of these hearing groups. The rationale for applying a smaller discount than suggested by audiograms is due in part to an observed characteristic of mammalian hearing that perceived equal loudness curves increasingly have less rapid rolloff outside the most sensitive hearing frequency range as sound levels increase. This is why, for example, C-weighting curves for humans, used for assessing loud sounds, are flatter than A-weighting curves, used for quiet to mid-level sounds. Additionally, out-of-band frequencies, though less audible, can still cause physical injury if pressure levels are sufficiently high. The M-weighting functions are, therefore, primarily intended to be applied at high sound levels where temporary or permanent hearing threshold shifts may occur. The use of M-weighting is considered precautionary, in the sense of overestimating potential effects, when it is applied to lower level impacts such as the onset of behavioral responses.

The M-weighting functions have unity gain (0 dB) through the passband and their high and low frequency rolloffs are approximately −12 dB/octave. The amplitude response in the frequency domain of the M-weighting functions is defined by:

$$G(f) = -20\log_{10}\left[\left(1+\frac{f_{lo}^2}{f^2}\right)\left(1+\frac{f^2}{f_{hi}^2}\right)\right] \tag{10}$$

The rolloff and passband of these filters are controlled by the two parameters f_{lo} and f_{hi}, which correspond to the estimated lower and upper hearing limits specific to each functional hearing group (Table 4). Figure 11 shows the decibel frequency weighting of the four underwater M-weighting functions. Low-, mid-, and high frequency cetaceans are present in the study area, but because pinnipeds are rare in these locations, we did not use the pinniped weighting function.

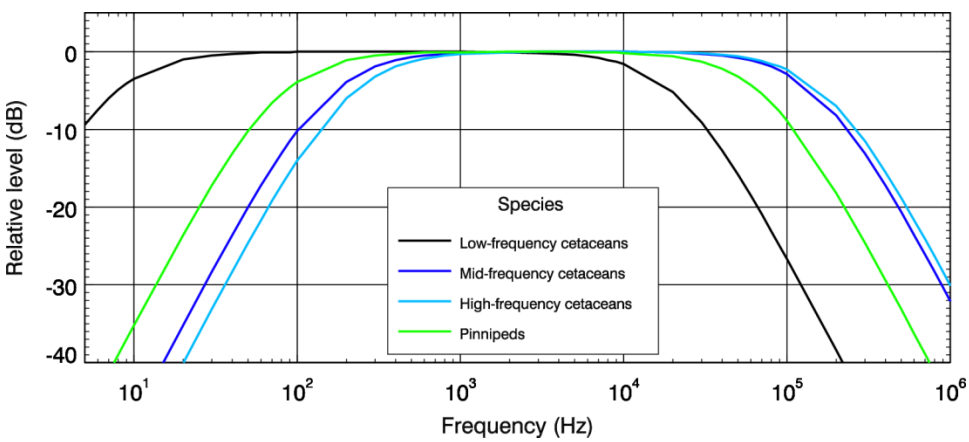


Figure 11. Standard M-weighting functions for low-, mid-, and high-frequency cetaceans, and for pinnipeds in water.

Table 4. Low- and high-frequency cut-off parameters of M-weighting curves for each marine mammal functional hearing group proposed by Southall et al. (2007).

Functional Hearing Group	f_{lo} (Hz)	f_{hi} (Hz)
Low-frequency cetaceans	7	22 000
Mid-frequency cetaceans	150	160 000
High-frequency cetaceans	200	180 000
Pinnipeds in water	75	75 000

5. Results

5.1. SEL Per-pulse Modeling Results

JASCO's Marine Operations Noise Model (MONM) was used to model the acoustic transmission loss (TL) in 1/3-octave bands from 10 to 1000 Hz. The received levels were calculated by adding the directional airgun array source levels computed from the Airgun Array Source Model (AASM) to the TL results. The unweighted 1/3-octave-band levels were summed to get the broadband SEL per pulse (dB re 1 μPa^2·s). Additionally, M-weighting was applied to the 1/3-octave-band levels and M-weighted broadband SELs per pulse (dB re 1 μPa^2·s) were computed. Contour levels and distances to various sound level thresholds were obtained by maximizing the sound levels over 100 receiver depths ranging from 2 m to 2000 m. Sample maps of unweighted and M-weighted SEL fields for a shelf site and two deep water sites (sites 8–10) are presented in Figures 12–13, 15–16, and 18–19. The tables of distances to various threshold levels (R_{max} and $R_{95\%}$) are shown in Tables 5–10. Figures 14, 17, and 20 compare received unweighted SEL per pulse (dB re 1 μPa^2·s) as a function of range and depth for two sound speed profiles at sites 8–10: August and December.

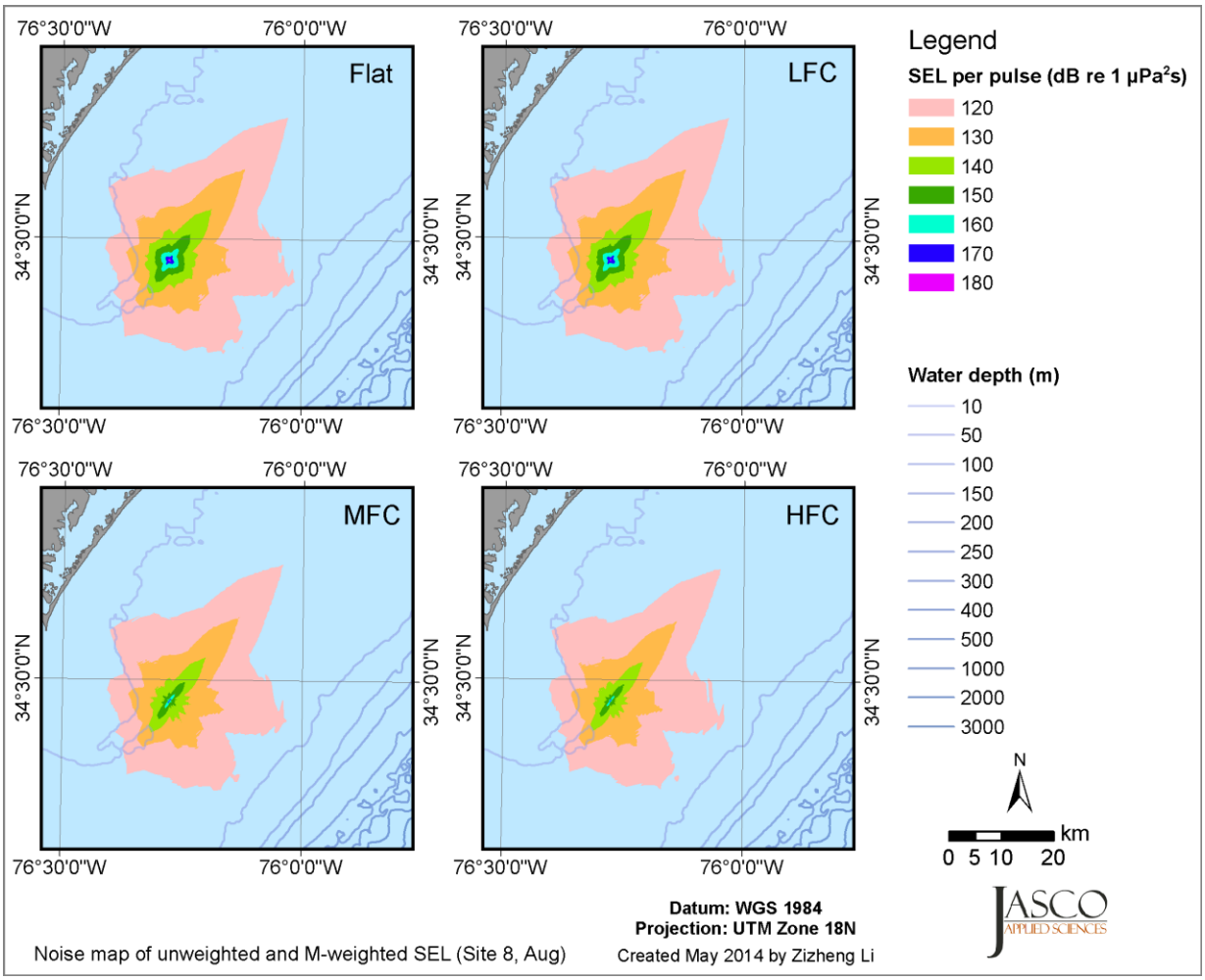


Figure 12. Contours of unweighted (flat-weighted) and M-weighted SEL per pulse (dB re 1 μPa^2·s) produced by the 6420 in^3 airgun array in August at site 8. Tow direction is 126°. Water depth is 30 m. The weighting functions used (Flat, LFC, MFC, HFC) appear in the top right of each panel.

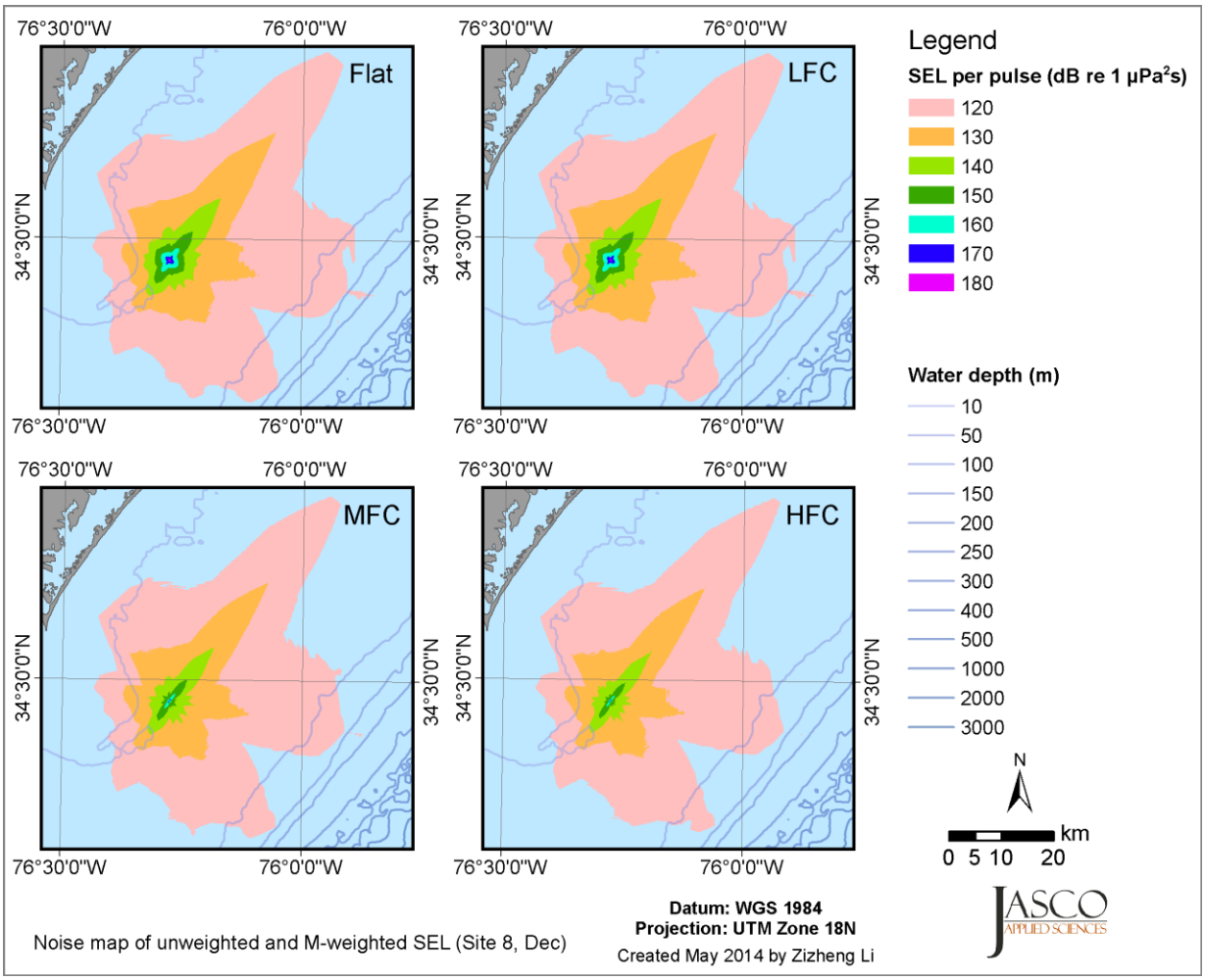


Figure 13. Contours of unweighted (flat-weighted) and M-weighted SEL per pulse (dB re 1 μPa^2·s) produced by the 6420 in^3 airgun array in December at site 8. Tow direction is 126°. Water depth is 30 m. The weighting functions used (Flat, LFC, MFC, HFC) appear in the top right of each panel.

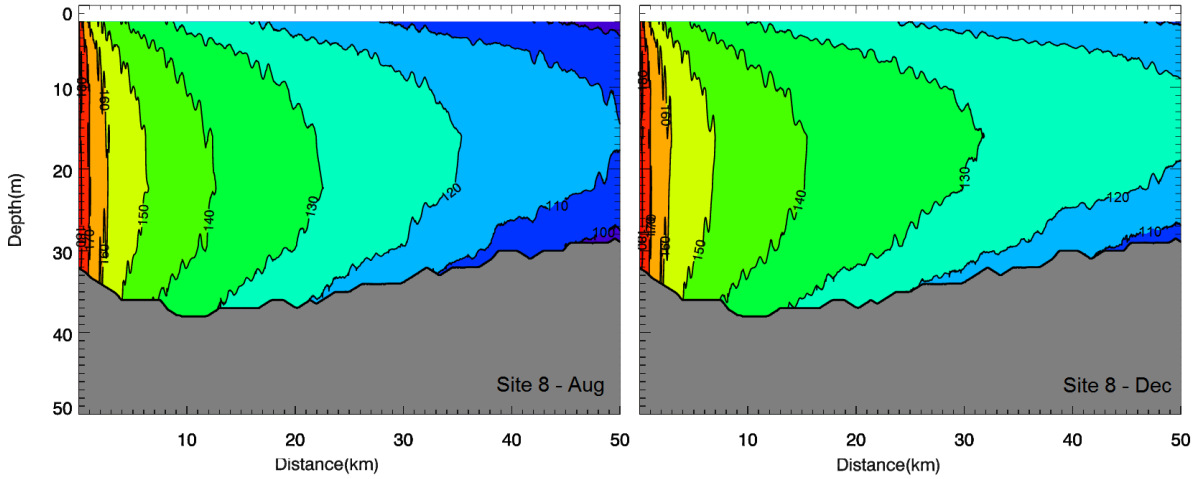


Figure 14. Unweighted SEL per pulse (dB re 1 μPa^2·s) as a function of range and depth for one transect (broadside: 36° clockwise from UTM North) from site 8. The sound speed profiles are for August (left) and December (right).

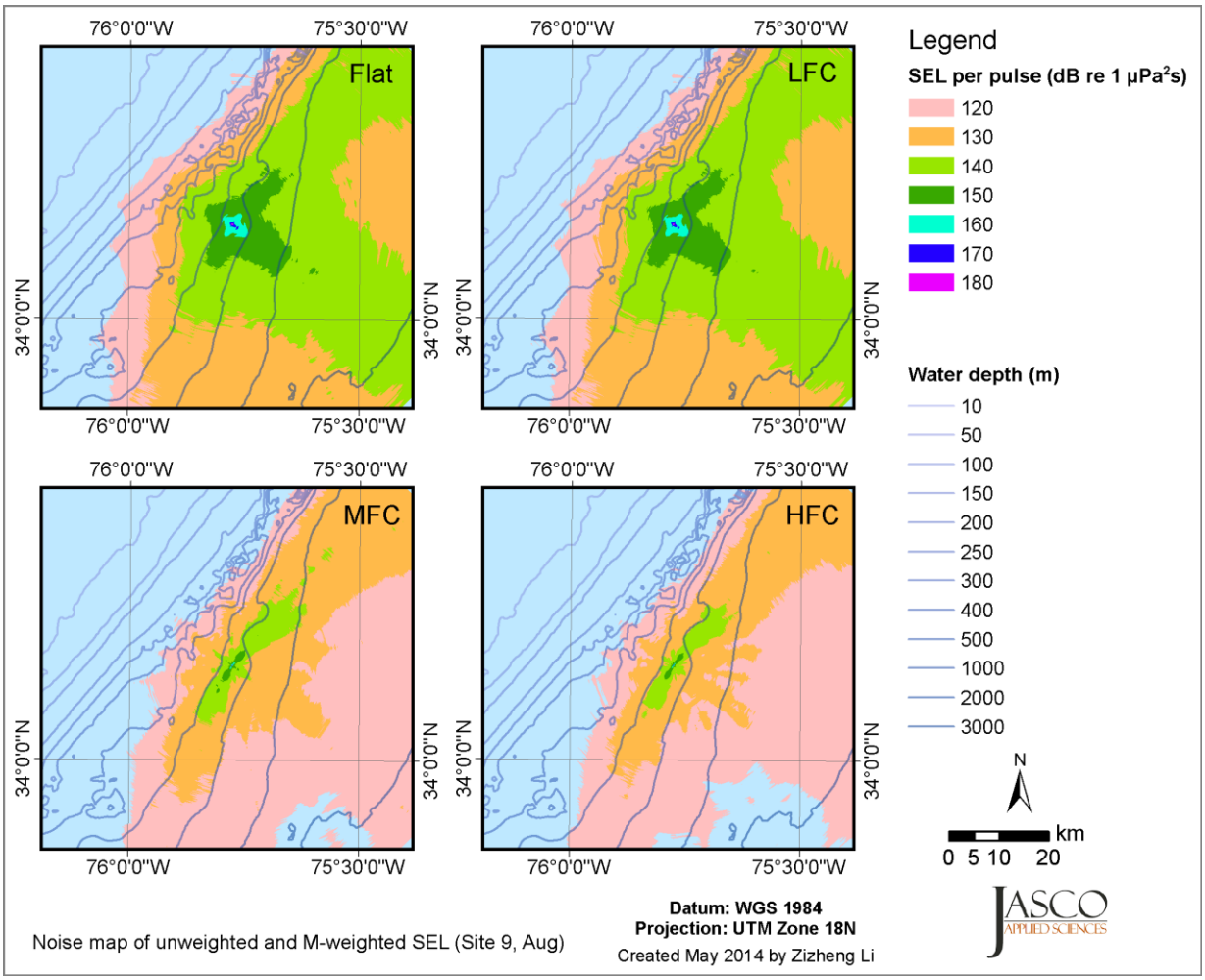


Figure 15. Contours of unweighted (flat-weighted) and M-weighted SEL per pulse (dB re 1 μPa^2·s) produced by the 6420 in^3 airgun array in August at site 9. Tow direction is 126°. Water depth is 700 m. The weighting functions used (Flat, LFC, MFC, HFC) appear in the top right of each panel.

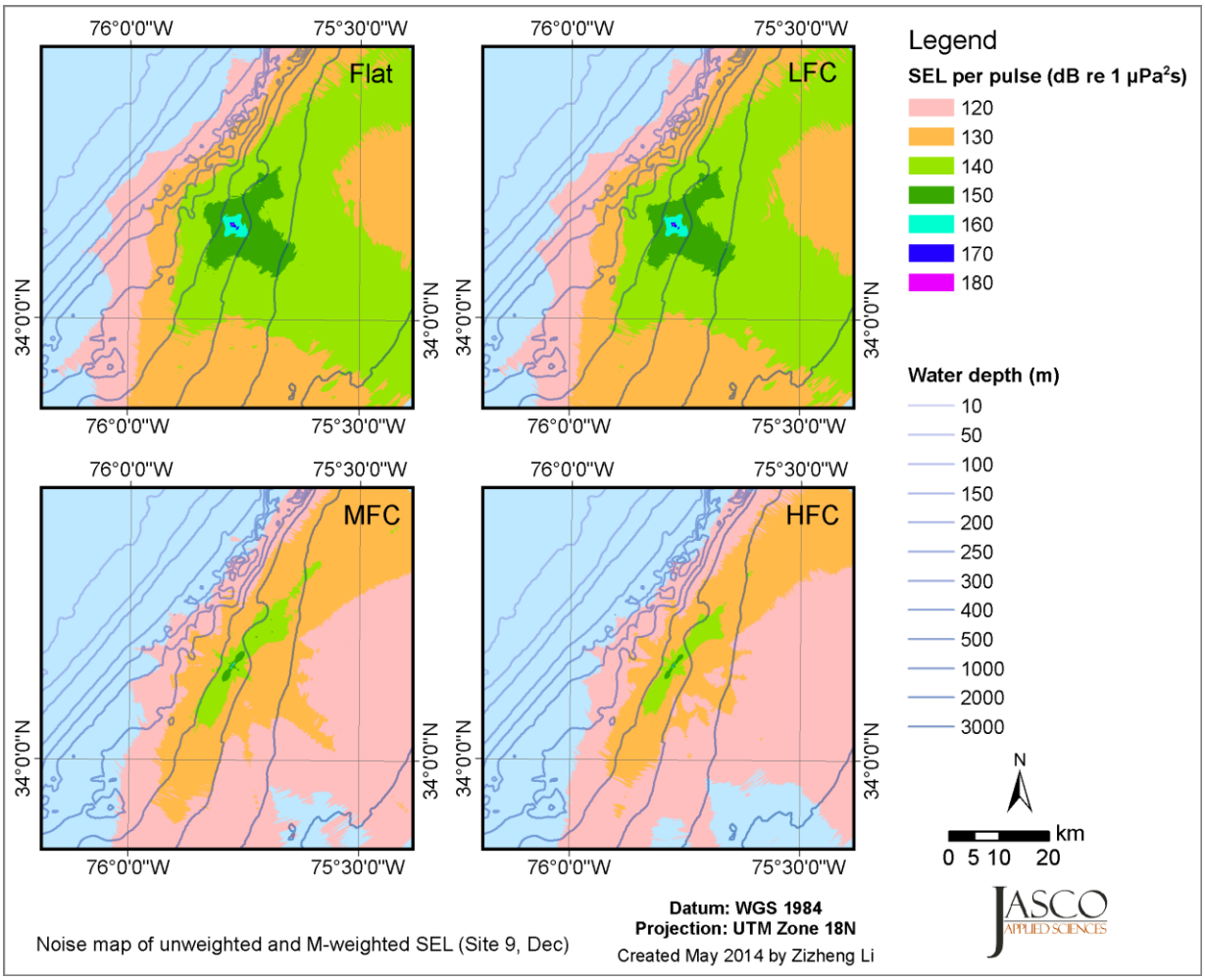


Figure 16. Contours of unweighted (flat-weighted) and M-weighted SEL per pulse (dB re 1 μPa^2·s) produced by the 6420 in^3 airgun array in December at site 9. Tow direction is 126°. Water depth is 700 m. The weighting functions used (Flat, LFC, MFC, HFC) appear in the top right of each panel.

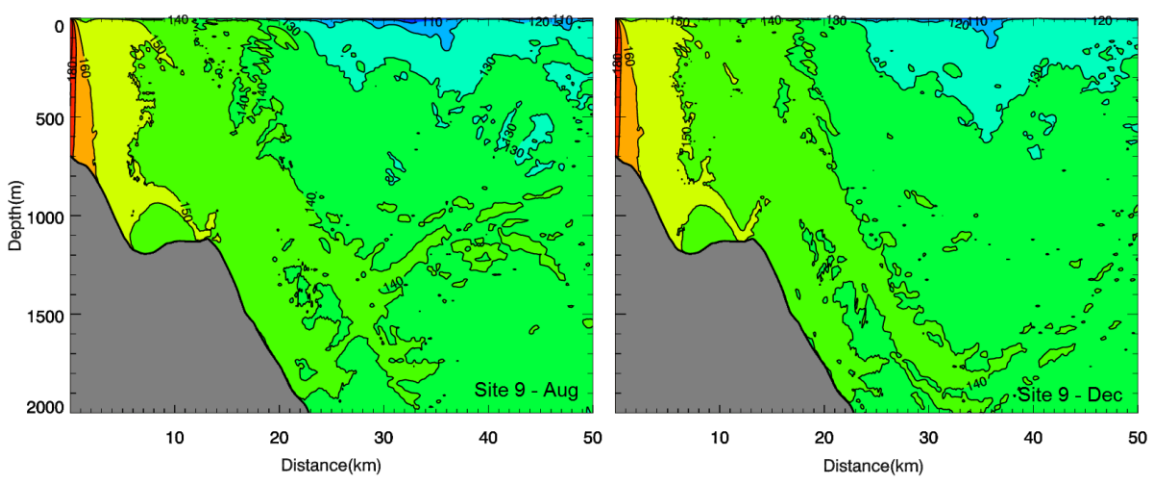


Figure 17. Unweighted SEL per pulse (dB re 1 μPa^2·s) as a function of range and depth for one transect (broadside: 36° clockwise from UTM North) from site 9. The sound speed profiles are for August (left) and December (right).

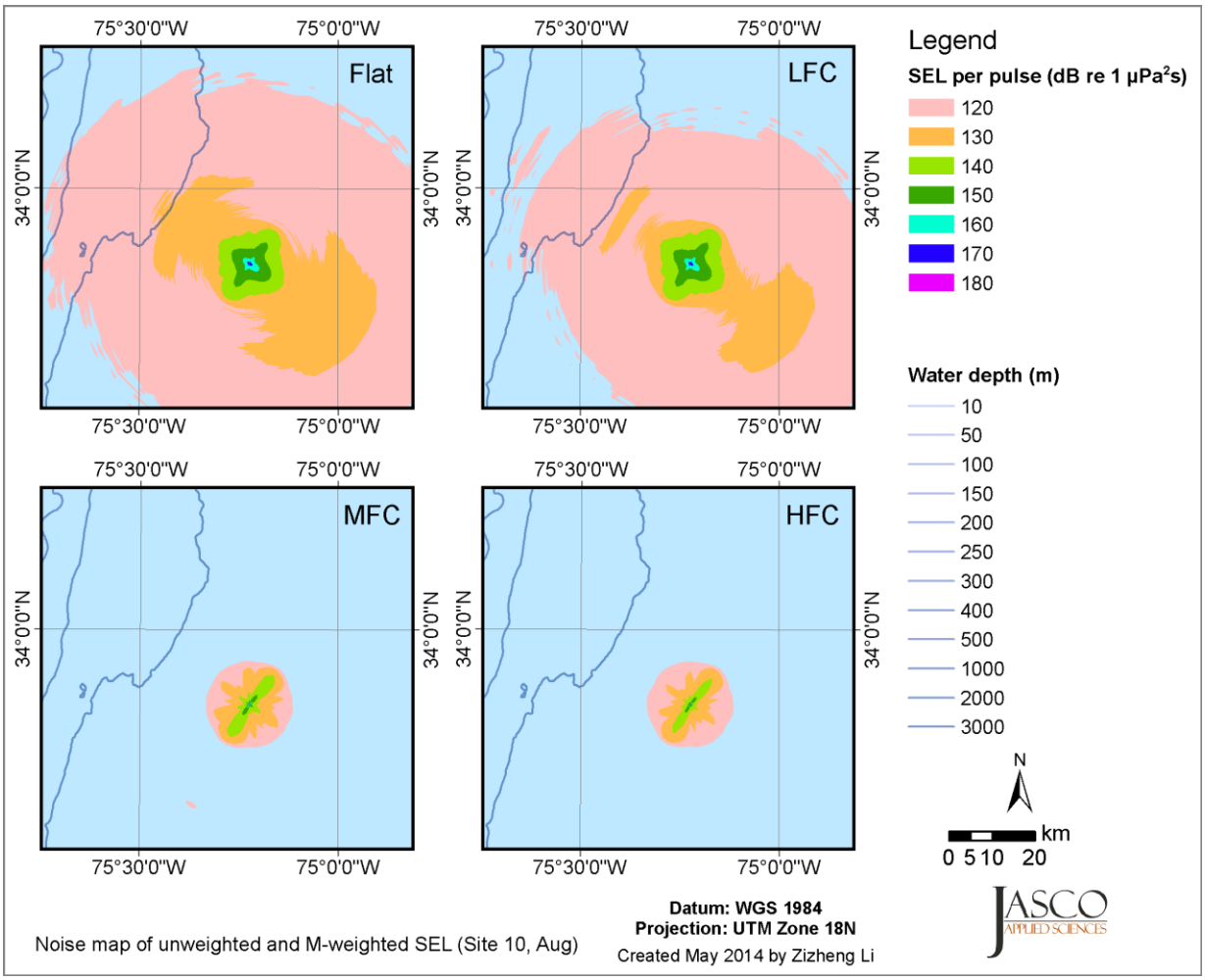


Figure 18. Contours of unweighted (flat-weighted) and M-weighted SEL per pulse (dB re 1 μPa^2·s) produced by the 6420 in^3 airgun array in August at site 10. Tow direction is 126°. Water depth is 3300 m. The weighting functions used (Flat, LFC, MFC, HFC) appear in the top right of each panel.

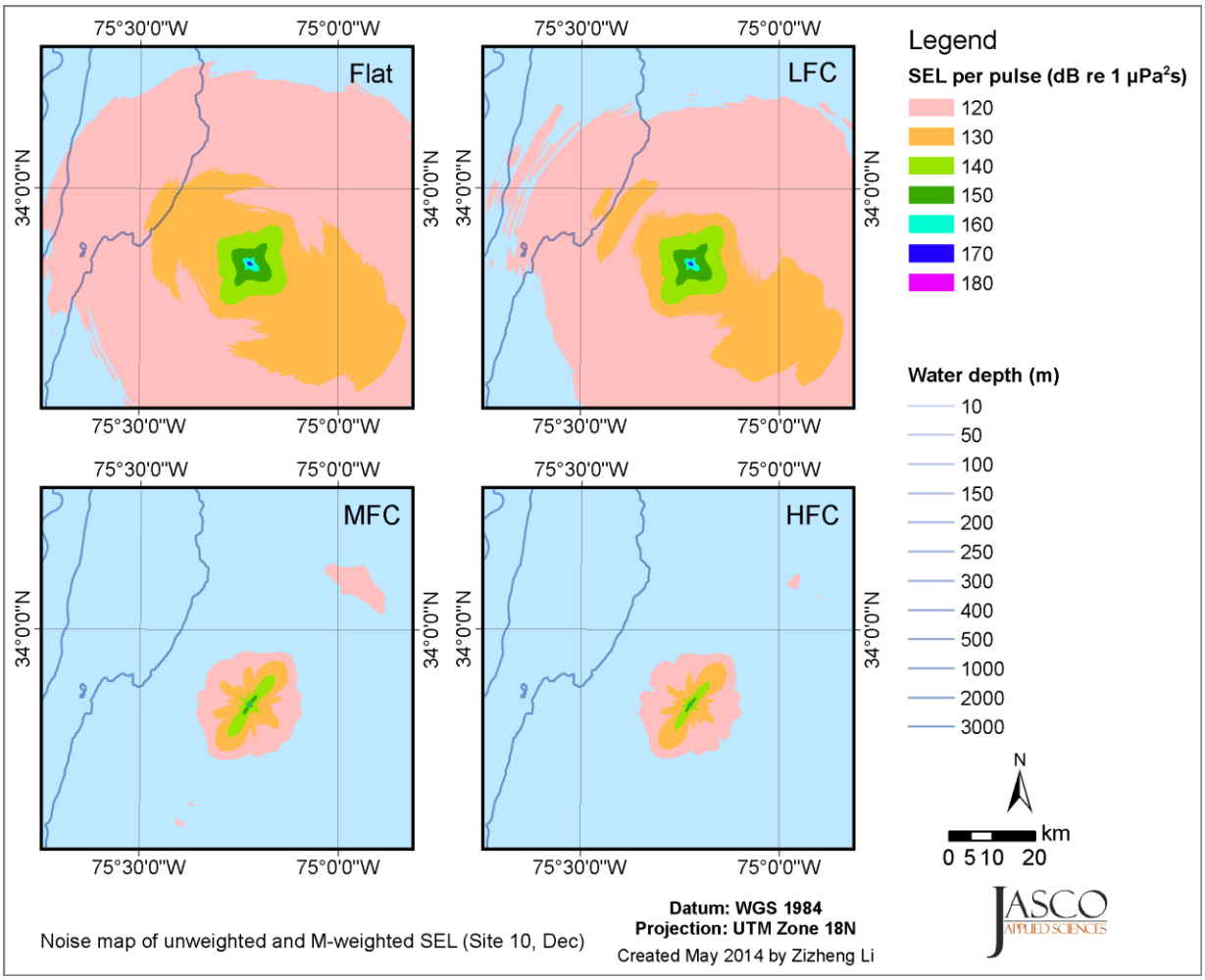


Figure 19. Contours of unweighted (flat-weighted) and M-weighted SEL per pulse (dB re 1 μPa^2·s) produced by the 6420 in^3 airgun array in December at site 10. Tow direction is 126°. Water depth is 3300 m. The weighting functions used (Flat, LFC, MFC, HFC) appear in the top right of each panel.

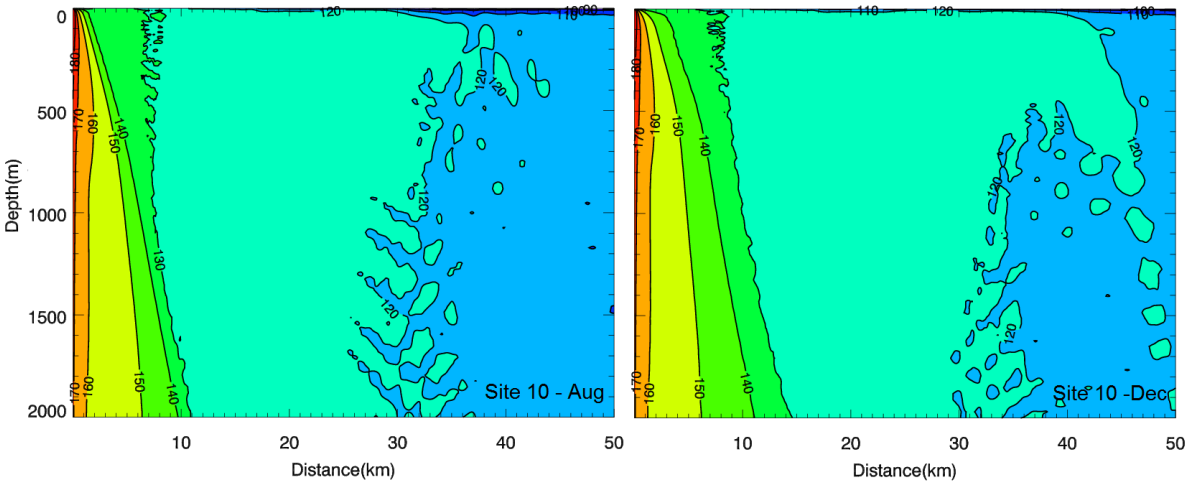


Figure 20. Unweighted SEL per pulse (dB re 1 μPa^2·s) as a function of range and depth for one transect (broadside: 36° clockwise from UTM North) at site 10. The sound speed profiles are for August (left) and December (right).

Table 5. Summary of predicted radii of unweighted (Flat-weighted) and M-weighted SEL per pulse for modeled sites on survey line 1.

Site	SEL (dB re 1 μPa^2·s)	Flat				LFC				MFC				HFC			
		Aug		Dec		Aug		Dec		Aug		Dec		Aug		Dec	
		R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
1	180	0.36	0.30	0.36	0.30	0.34	0.28	0.34	0.28	0.08	0.08	0.08	0.08	0.06	0.06	0.06	0.06
	170	1.14	0.93	1.16	0.96	1.04	0.90	1.04	0.92	0.44	0.39	0.46	0.40	0.34	0.31	0.36	0.32
	160	2.68	2.16	2.90	2.28	2.66	2.12	2.90	2.26	1.52	1.32	1.60	1.37	1.14	1.03	1.34	1.06
2	180	0.28	0.23	0.28	0.24	0.26	0.22	0.26	0.22	0.08	0.08	0.08	0.08	0.06	0.06	0.06	0.06
	170	0.90	0.75	0.90	0.76	0.84	0.72	0.84	0.72	0.28	0.24	0.28	0.24	0.22	0.20	0.22	0.20
	160	3.45	2.95	3.43	2.93	3.39	2.91	3.39	2.90	0.88	0.77	0.86	0.76	0.66	0.58	0.66	0.58
3	180	0.28	0.23	0.28	0.23	0.26	0.22	0.26	0.22	0.08	0.08	0.08	0.08	0.06	0.06	0.06	0.06
	170	0.88	0.74	0.88	0.74	0.82	0.70	0.83	0.70	0.28	0.24	0.28	0.25	0.22	0.20	0.22	0.20
	160	3.72	3.16	3.72	3.15	3.64	3.13	3.62	3.12	0.88	0.78	0.86	0.76	0.68	0.58	0.66	0.58

Table 6. Summary of predicted radii of unweighted (Flat-weighted) and M-weighted SEL per pulse for modeled sites on survey line 2.

Site	SEL (dB re 1 μPa^2·s)	Flat				LFC				MFC				HFC			
		Aug		Dec		Aug		Dec		Aug		Dec		Aug		Dec	
		R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
4	180	0.35	0.30	0.36	0.31	0.34	0.29	0.35	0.30	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06
	170	1.12	0.93	1.14	0.95	1.05	0.88	1.08	0.91	0.43	0.37	0.43	0.38	0.34	0.31	0.34	0.31
	160	2.50	2.08	3.00	2.34	2.48	2.02	2.98	2.33	1.42	1.22	1.73	1.35	1.18	0.97	1.25	1.10
5	180	0.27	0.23	0.27	0.23	0.26	0.23	0.26	0.23	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06
	170	1.42	1.32	1.42	1.32	1.39	1.29	1.39	1.30	0.27	0.24	0.28	0.26	0.21	0.18	0.21	0.18
	160	3.73	3.06	3.86	3.20	3.66	2.70	3.69	2.81	0.87	0.76	0.85	0.74	0.65	0.57	0.65	0.58
6	180	0.27	0.23	0.27	0.23	0.26	0.23	0.26	0.23	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06
	170	0.87	0.73	0.87	0.74	0.81	0.69	0.81	0.69	0.27	0.24	0.28	0.26	0.21	0.18	0.21	0.20
	160	2.81	2.39	2.83	2.41	2.70	2.30	2.71	2.32	0.88	0.77	0.87	0.76	0.65	0.58	0.65	0.58
7	180	0.27	0.23	0.27	0.23	0.26	0.23	0.26	0.23	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06
	170	0.85	0.73	0.85	0.73	0.81	0.69	0.81	0.69	0.27	0.24	0.28	0.26	0.21	0.18	0.21	0.20
	160	2.78	2.36	2.80	2.37	2.67	2.24	2.67	2.24	0.89	0.78	0.87	0.76	0.65	0.58	0.65	0.58

Table 7. Summary of predicted radii of unweighted (Flat-weighted) and M-weighted SEL per pulse for modeled sites on survey line 3.

Site	SEL (dB re 1 µPa^2·s)	Flat				LFC				MFC				HFC			
		Aug		Dec		Aug		Dec		Aug		Dec		Aug		Dec	
		R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
8	180	0.40	0.34	0.40	0.34	0.37	0.32	0.38	0.33	0.13	0.12	0.12	0.11	0.06	0.06	0.06	0.06
	170	1.09	0.93	1.09	0.94	1.04	0.90	1.04	0.91	0.50	0.45	0.50	0.45	0.34	0.30	0.34	0.30
	160	2.77	2.20	2.92	2.32	2.70	2.21	2.92	2.32	1.78	1.45	1.80	1.53	1.31	1.13	1.35	1.17
9	180	0.27	0.23	0.28	0.23	0.26	0.23	0.26	0.23	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06
	170	1.46	1.36	1.47	1.36	1.43	1.34	1.43	1.34	0.28	0.24	0.28	0.25	0.21	0.20	0.21	0.20
	160	3.73	3.13	4.21	3.10	3.65	3.05	3.61	3.01	0.88	0.77	0.87	0.76	0.65	0.58	0.66	0.58
10	180	0.27	0.23	0.27	0.23	0.26	0.23	0.26	0.23	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06
	170	0.87	0.73	0.87	0.73	0.82	0.69	0.82	0.69	0.28	0.24	0.28	0.25	0.21	0.20	0.21	0.20
	160	2.76	2.33	2.76	2.34	2.63	2.22	2.63	2.22	0.89	0.78	0.87	0.76	0.65	0.58	0.66	0.58
11	180	0.27	0.23	0.28	0.23	0.26	0.23	0.26	0.23	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06
	170	0.87	0.73	0.87	0.74	0.83	0.69	0.83	0.70	0.28	0.25	0.28	0.25	0.21	0.19	0.21	0.20
	160	2.76	2.33	2.77	2.34	2.63	2.21	2.63	2.22	0.91	0.80	0.87	0.76	0.68	0.59	0.66	0.58

Table 8. Summary of predicted radii of unweighted (Flat-weighted) and M-weighted SEL per pulse for modeled sites on survey line 4.

Site	SEL (dB re 1 µPa^2·s)	Flat				LFC				MFC				HFC			
		Aug		Dec		Aug		Dec		Aug		Dec		Aug		Dec	
		R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
12	180	0.39	0.33	0.39	0.34	0.37	0.31	0.39	0.33	0.12	0.11	0.12	0.11	0.05	0.05	0.05	0.05
	170	1.04	0.86	1.06	0.92	1.00	0.83	1.01	0.90	0.47	0.43	0.48	0.44	0.35	0.30	0.35	0.31
	160	2.13	1.79	2.91	2.34	2.12	1.76	2.91	2.34	1.30	1.15	1.85	1.56	1.07	0.92	1.36	1.17
13	180	0.41	0.36	0.43	0.38	0.39	0.34	0.41	0.36	0.07	0.07	0.07	0.07	0.05	0.05	0.05	0.05
	170	1.31	1.16	1.33	1.17	1.28	1.14	1.30	1.15	0.28	0.24	0.28	0.25	0.21	0.19	0.21	0.20
	160	3.56	2.87	3.88	2.99	3.47	2.78	3.69	2.86	1.81	1.52	1.60	1.23	0.91	0.81	0.94	0.84
14	180	0.28	0.23	0.28	0.23	0.26	0.22	0.26	0.23	0.07	0.07	0.07	0.07	0.05	0.05	0.05	0.05
	170	0.87	0.73	0.87	0.73	0.82	0.69	0.82	0.69	0.28	0.24	0.28	0.25	0.21	0.19	0.21	0.20
	160	2.83	2.38	2.84	2.40	2.70	2.26	2.71	2.27	0.88	0.78	0.86	0.76	0.67	0.58	0.66	0.58

Table 9. Summary of predicted radii of unweighted (Flat-weighted) and M-weighted SEL per pulse for modeled sites on survey line 5.

Site	SEL (dB re 1 µPa^2·s)	Flat				LFC				MFC				HFC			
		Aug		Dec		Aug		Dec		Aug		Dec		Aug		Dec	
		R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
15	180	0.30	0.26	0.30	0.26	0.27	0.23	0.27	0.23	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06
	170	1.09	0.96	1.09	0.95	1.08	0.95	1.08	0.94	0.28	0.24	0.28	0.24	0.21	0.20	0.21	0.20
	160	3.25	2.86	3.37	2.88	3.24	2.82	3.23	2.83	1.21	1.08	1.25	1.09	1.02	0.92	1.02	0.91
16	180	0.27	0.23	0.27	0.23	0.26	0.22	0.26	0.22	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06
	170	0.91	0.76	0.91	0.77	0.84	0.70	0.84	0.70	0.27	0.24	0.28	0.24	0.21	0.20	0.21	0.20
	160	2.20	1.81	2.22	1.82	2.14	1.77	2.17	1.78	0.85	0.75	0.84	0.74	0.65	0.57	0.65	0.57

Table 10. Summary of predicted radii of unweighted (Flat-weighted) and M-weighted SEL per pulse for modeled sites on survey line 6.

Site	SEL (dB re 1 µPa^2·s)	Flat				LFC				MFC				HFC			
		Aug		Dec		Aug		Dec		Aug		Dec		Aug		Dec	
		R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
17	180	0.28	0.24	0.28	0.24	0.26	0.23	0.26	0.22	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06
	170	0.87	0.73	0.88	0.74	0.83	0.70	0.84	0.70	0.25	0.23	0.27	0.25	0.19	0.17	0.21	0.19
	160	2.92	2.41	2.92	2.45	2.68	2.28	2.77	2.31	0.94	0.83	0.85	0.76	0.70	0.62	0.66	0.58
18	180	0.28	0.24	0.28	0.24	0.26	0.22	0.26	0.22	0.08	0.08	0.08	0.08	0.06	0.06	0.06	0.06
	170	0.87	0.73	0.87	0.73	0.83	0.69	0.84	0.70	0.26	0.24	0.28	0.25	0.21	0.19	0.22	0.19
	160	2.81	2.33	2.83	2.34	2.66	2.21	2.66	2.22	0.87	0.80	0.85	0.77	0.66	0.59	0.66	0.59

5.2. rms SPL Modeling Results

The United States National Marine Fisheries Service (NMFS) currently assesses airgun noise impacts based on criteria expressed in terms of the rms SPL metric. These criteria assume that for impulsive sound sources, a broadband received rms SPL of 160 dB re 1 µPa or greater may disrupt marine mammal behavioral patterns, and that cetaceans and pinnipeds can experience temporary or permanent hearing impairment at 180 and 190 dB re 1 µPa rms SPL, respectively (NMFS 2014). These criteria account for both the energy and the length of the pulse (Equation 3), and they have been widely used to assess the effects of seismic survey noise. They do not, however, account for exposure duration, frequency composition of the sound, repetition rate, or the hearing ability of the animals. Contours of rms SPL for each modeled site were calculated by applying the rms SPL–SEL offsets (Section 4.4) to the SELs. Figure 21 shows a sample map of rms SPL contours for sites 8–11. The rms SPL contours for other sites are shown in Appendix B. The R_{max} and $R_{95\%}$ of rms SPL for each site are tabulated in Tables 11–16.

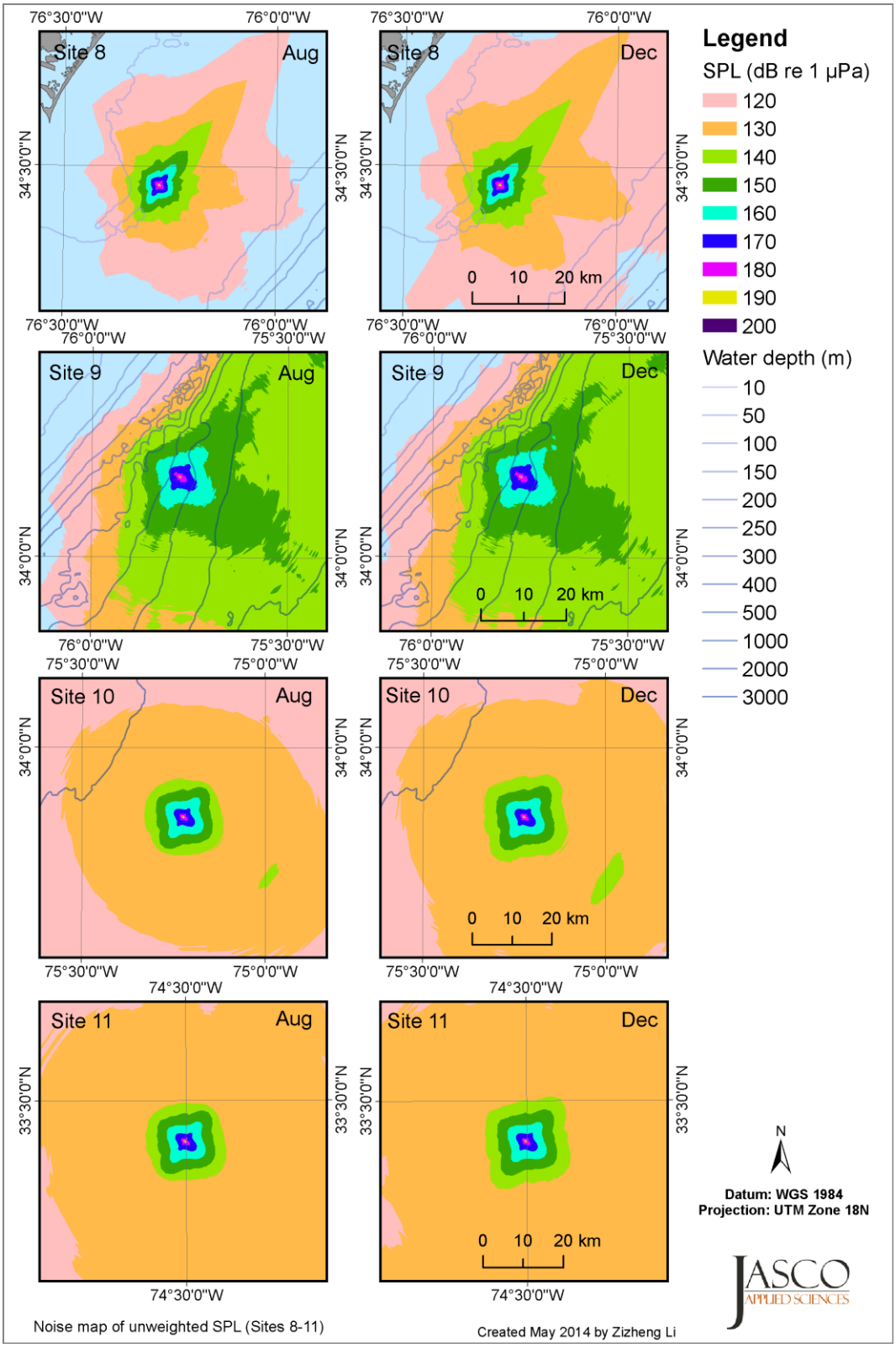


Figure 21. Contours of rms SPL (dB re 1 µPa) produced by the 6420 in^3 airgun array at sites 8−11; August (left) and December (right). Tow direction is 126°. The modeled site numbers are on the top left of each panel.

Table 11. Summary of predicted SPL radii for modeled sites 1–3 on survey line 1. The water depth is in parentheses after each site number.

SPL (dB re 1 µPa)	Site 1 (45 m)				Site 2 (820 m)				Site 3 (1000 m)			
	Aug		Dec		Aug		Dec		Aug		Dec	
	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
190	0.54	0.47	0.54	0.48	0.52	0.44	0.52	0.44	0.52	0.44	0.52	0.44
180	1.30	1.11	1.32	1.12	1.98	1.71	1.98	1.72	2.08	1.88	2.10	1.89
170	2.92	2.37	3.20	2.56	4.38	3.49	4.42	3.56	4.38	3.62	4.36	3.59
160	5.74	4.74	6.50	5.27	9.08	7.47	9.12	7.49	8.99	7.53	9.04	7.48

Table 12. Summary of predicted SPL radii for modeled sites 4–7 on survey line 2. The water depth is in parentheses after each site number.

SPL (dB re 1 µPa)	Site 4 (40 m)				Site 5 (650 m)				Site 6 (1500 m)				Site 7 (2600 m)			
	Aug		Dec		Aug		Dec		Aug		Dec		Aug		Dec	
	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
190	0.54	0.47	0.54	0.47	0.51	0.44	0.51	0.44	0.51	0.44	0.51	0.44	0.51	0.44	0.51	0.44
180	1.29	1.09	1.32	1.12	2.27	1.53	2.27	1.55	1.48	1.24	1.48	1.24	1.43	1.22	1.45	1.22
170	2.74	2.25	3.08	2.57	4.59	3.81	4.61	3.85	3.47	2.89	3.49	2.92	3.54	2.93	3.55	2.95
160	5.34	4.20	6.39	5.22	8.62	7.27	8.65	7.37	6.12	5.21	6.05	5.25	6.26	5.42	6.11	5.39

Table 13. Summary of predicted SPL radii for modeled sites 8–11 on survey line 3. The water depth is in parentheses after each site number.

SPL (dB re 1 µPa)	Site 8 (30 m)				Site 9 (700 m)				Site 10 (3300 m)				Site 11 (4200 m)			
	Aug		Dec		Aug		Dec		Aug		Dec		Aug		Dec	
	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
190	0.54	0.45	0.54	0.45	0.52	0.44	0.53	0.45	0.51	0.44	0.52	0.44	0.52	0.44	0.52	0.44
180	1.28	1.10	1.31	1.12	1.93	1.65	1.94	1.67	1.45	1.22	1.45	1.22	1.44	1.21	1.45	1.22
170	3.05	2.39	3.19	2.51	4.74	3.96	4.73	3.97	3.50	2.93	3.52	2.94	3.50	2.92	3.51	2.94
160	5.79	4.48	6.32	4.77	9.86	8.21	12.67	8.25	6.25	5.41	6.11	5.38	6.19	5.39	6.12	5.36

Table 14. Summary of predicted SPL radii for modeled sites 12–14 on survey line 4. The water depth is in parentheses after each site number.

SPL (dB re 1 µPa)	Site 12 (30 m)				Site 13 (140 m)				Site 14 (2400 m)			
	Aug		Dec		Aug		Dec		Aug		Dec	
	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
190	0.53	0.44	0.54	0.46	0.39	0.34	0.41	0.36	0.51	0.43	0.51	0.43
180	1.20	1.02	1.29	1.10	1.26	1.11	1.27	1.12	1.48	1.23	1.48	1.23
170	2.36	1.95	3.12	2.52	2.93	2.30	3.00	2.38	3.53	2.95	3.56	2.97
160	4.04	3.25	6.08	4.86	8.27	6.47	9.83	6.75	6.33	5.46	6.22	5.45

Table 15. Summary of predicted SPL radii for modeled sites 15–16 on survey line 5. The water depth is in parentheses after each site number.

SPL (dB re 1 µPa)	Site 15 (190 m)				Site 16 (870 m)			
	Aug		Dec		Aug		Dec	
	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
190	0.28	0.24	0.28	0.24	0.51	0.43	0.51	0.43
180	1.07	0.93	1.05	0.92	1.48	1.25	1.49	1.25
170	3.12	2.34	3.14	2.36	2.77	2.40	2.76	2.40
160	6.33	4.95	6.60	5.17	4.21	3.63	4.37	3.79

Table 16. Summary of predicted SPL radii for modeled sites 17–18 on survey line 6. The water depth is in parentheses after each site number.

SPL (dB re 1 µPa)	Site 15 (2200 m)				Site 16 (4180 m)			
	Aug		Dec		Aug		Dec	
	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)	R_{max} (km)	$R_{95\%}$ (km)
190	0.51	0.44	0.51	0.44	0.51	0.43	0.52	0.44
180	1.49	1.24	1.50	1.25	1.47	1.22	1.47	1.22
170	3.59	2.95	3.66	3.00	3.54	2.93	3.56	2.95
160	6.49	5.60	6.40	5.57	6.09	5.40	6.21	5.38

6. Discussion and Conclusion

This report presents the results of an acoustic modeling study performed to estimate the sound fields generated by a 6420 in^3 seismic airgun array off the coast of the eastern United States. The model was run at 18 representative locations within the planned survey area.

In this study, the sound isopleth maps showed that the shape of the sound field depends on the airgun array directionality as well as on the propagation environment.

At shallow water sites, the sound field at long distances is dominated by sound frequencies between 100 to 500 Hz. This intermediate-frequency sound field varies a lot with direction because of the correspondingly high directivity of the source at these frequencies (Figure 5, Section 4.1). For example, in the 100–500 Hz frequency range, the sound from the airgun array at site 8 propagates further in the broadside direction than in the endfire direction (Figure 22). Lower frequency energy is more rapidly attenuated and so is not able to propagate to very long distances.

In contrast, the long-range spectra at a deeper-water site such as site 9 (Figure 23) contain more low-frequency energy, resulting in longer propagation distances. The shape of the sound field at site 9 is also more strongly influenced by the directionality of the airgun array at frequencies in the tens of Hz (Figure 5, Section 4.1). Applying M-weighting also affects the extent and shape of the sound fields because both the source levels and the transmission loss are computed as a function of frequency as well as azimuth relative to the array heading.

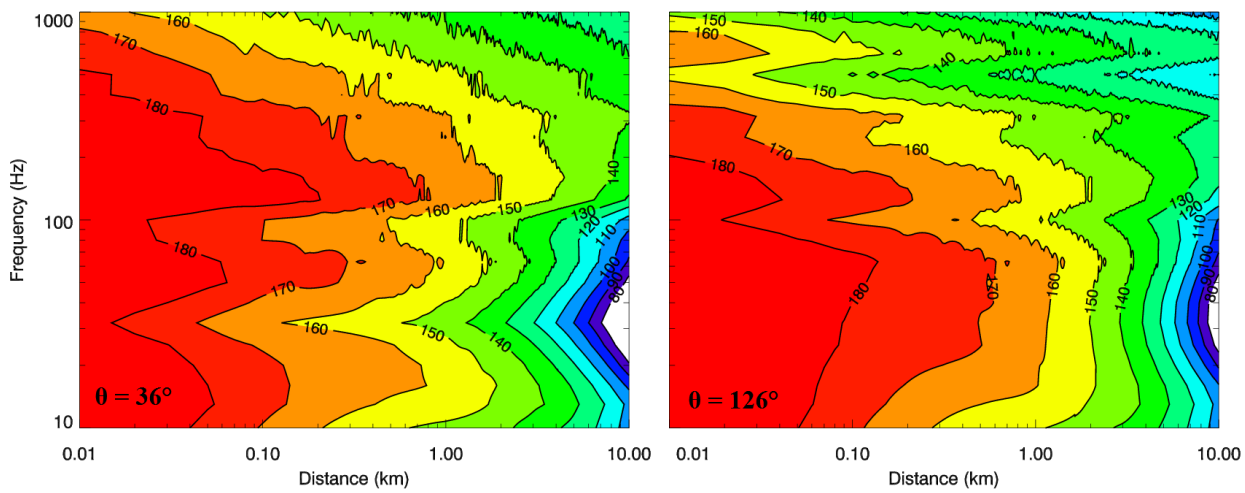


Figure 22. Predicted 1/3-octave-band unweighted SEL per pulse (dB re 1 μPa^2·s) as a function of range for December at site 8 (water depth of 30 m). The maximum-over-depth rule was applied. (Left) azimuth angles θ = 36°: the radial is across the array tow direction; and (right) θ = 126°: the radial is along the array tow direction.

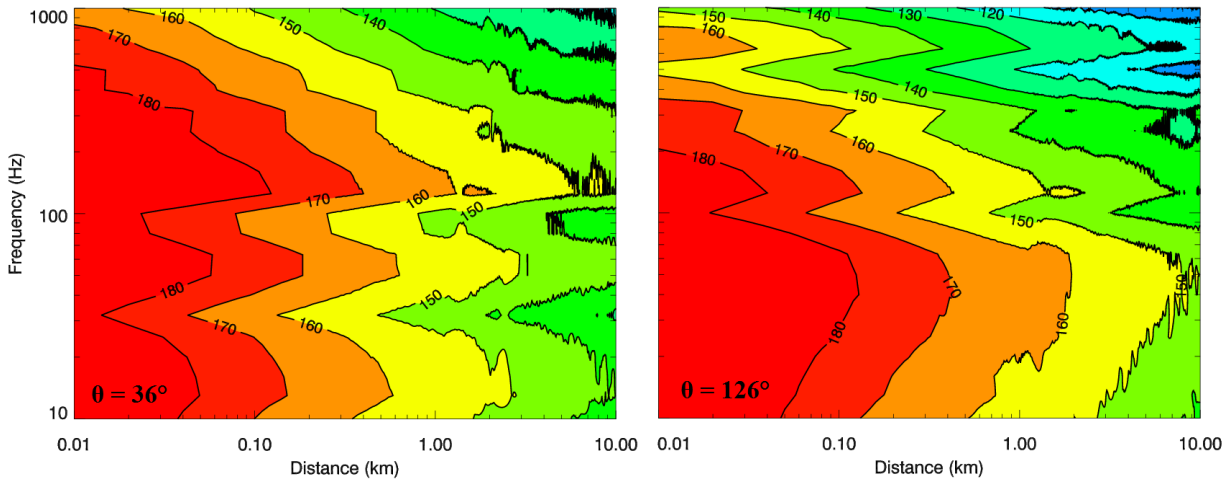


Figure 23. Predicted 1/3-octave-band unweighted SEL per pulse (dB re 1 µPa^2·s) as a function of range for December at site 9 (water depth of 700 m). The maximum-over-depth rule was applied. (Left) azimuth angles θ = 36°: the radial is across the array tow direction; and (right) θ = 126°: the radial is along the array tow direction.

Table 17 summarizes the $R_{95\%}$ distances of rms SPL for August and December at each modeled site. As discussed in Section 4.3.2, the December SSP has a deeper and more upward-refracting surface layer than the August SSP, which could support longer-range propagation by minimizing bottom loss. The differences in the radii between December and August are generally small for all but the longer-ranges at the shallower sites (e.g., sites 1, 4, 8, and 12), because both SSPs have dominant downward refraction for depths greater than approximately 100 m. The radii are smaller when the source operates in shallow water, such as at sites 1, 4, 8, 12, and 15. These sites have mostly sand sediments, which are more acoustically reflective, but low frequencies propagate relatively poorly in shallow water. The deep sites over the continental slope and ocean basin (sites 6, 7, 10, 11, 14, and 16–18) are located over clay sediments, which are associated with greater bottom loss, but this is balanced by the better low-frequency propagation in deep water. The largest unweighted radii are typically associated with sites in intermediate water depth (sites 2, 3, 5, 9, and 13); this is particularly true of the 160 dB re 1 µPa contour. These sites are located over sand sediments, which are more acoustically reflective. At intermediate water depths, low-frequency sounds are no longer stripped out, and longer-range propagation can be increased by sound channeling resulting from sound reflecting from the sea surface and seabed (depending on the sound speed profiles and sediment types). The largest 160 dB re 1 µPa threshold distance ($R_{95\%}$) predicted, approximately 8 km, occurred at site 9, a location with a sandy bottom and a water depth of 700 m. The specific shape and extent of the sound fields varies considerably from site to site, depending on the local sound speed profile, sediment properties, and bathymetry.

Table 17: Summary of predicted SPL radii ($R_{95\%}$) for modeled sites 1–18.

SPL (dB re 1 µPa)	**Radii $R_{95\%}$ (km)**																	
	Modeled Sites																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
August																		
190	0.47	0.44	0.44	0.47	0.44	0.44	0.44	0.45	0.44	0.44	0.44	0.44	0.34	0.43	0.24	0.43	0.44	0.43
180	1.11	1.71	1.88	1.09	1.53	1.24	1.22	1.10	1.65	1.22	1.21	1.02	1.11	1.23	0.93	1.25	1.24	1.22
160	4.74	7.47	7.53	4.20	7.27	5.21	5.42	4.48	8.21	5.41	5.39	3.25	6.47	5.46	4.95	3.63	5.60	5.40
December																		
190	0.48	0.44	0.44	0.47	0.44	0.44	0.44	0.45	0.45	0.44	0.44	0.46	0.36	0.43	0.24	0.43	0.44	0.44
180	1.12	1.72	1.89	1.12	1.55	1.24	1.22	1.12	1.67	1.22	1.22	1.10	1.12	1.23	0.92	1.25	1.25	1.22
160	5.27	7.49	7.48	5.22	7.37	5.25	5.39	4.77	8.25	5.38	5.36	4.86	6.75	5.45	5.17	3.79	5.57	5.38

Glossary

90%-energy time window
The time interval over which the cumulative energy rises from 5% to 95% of the total pulse energy. This interval contains 90% of the total pulse energy. Symbol: T_{90}.

90% rms SPL
The root-mean-square sound pressure levels calculated over the 90%-energy time window of a pulse. Used only for pulsed sounds.

azimuth
A horizontal angle relative to a reference direction, often magnetic north or the direction of travel.

broadband sound level
The total sound pressure level measured over a specified frequency range. If the frequency range is unspecified, it refers to the entire measurement range.

broadside direction
Perpendicular to the travel direction of a source.

decibel
A logarithmic unit of the ratio of a quantity to a reference quantity of the same kind. Unit symbol: decibel (dB).

endfire direction
Parallel to the travel direction of a source.

ensonified
Exposed to sound.

frequency
The rate of oscillation of a periodic function measured in units of cycles-per-unit-time. The reciprocal of the period. Unit: hertz (Hz). Symbol: f. For example, 1 Hz = 1 cycle per second.

geoacoustic
Relating to the acoustic properties of the seabed.

M-weighting
The process of band-pass filtering loud sounds that reduces the importance of inaudible or less-audible frequencies for broad classes of marine mammals. “Generalized frequency weightings for various functional hearing groups of marine mammals, allowing for their functional bandwidths and appropriate in characterizing auditory effects of strong sounds” (Southall et al. 2007).

noise
Unwanted sound that interferes with detecting other sounds.

parabolic equation (PE) method
A computationally-efficient solution to the acoustic wave equation that is used to model transmission loss (TL). The PE approximation omits effects of back-scattered sound, which simplifies computing TL. The effect of back-scattered sound is negligible for most ocean-acoustic propagation problems.

peak sound pressure level (peak SPL)
The maximum instantaneous sound pressure level, in a stated frequency band, within a stated period. Also called zero-to-peak sound pressure level. Unit: decibel (dB). Symbol: L_{pk}.

peak-to-peak sound pressure level (peak-to-peak SPL)
The difference between the maximum and minimum instantaneous sound pressure levels. Unit: decibel (dB). Symbol: $L_{\mathrm{pk\text{-}pk}}$.

point source
A source that radiates sound as if from a single point (ANSI S1.1-1994 R1999).

pressure, acoustic
The deviation from the ambient hydrostatic pressure caused by a sound wave. Also called overpressure. Unit: pascal (Pa).

pressure, hydrostatic
The pressure at any given depth in a static liquid that is the result of the weight of the liquid acting on a unit area at that depth, plus any pressure acting on the surface of the liquid. Unit: pascal (Pa).

rms
root mean square.

rms sound pressure level (rms SPL)
The root-mean-square average of the instantaneous sound pressure (symbol is L_p) as measured over some specified time interval (symbol T). For continuous sound, the time interval is one second.

See also 90% rms SPL.

shear wave
A mechanical vibration wave where the direction of particle motion is perpendicular to the direction of propagation. Sometimes referred to as a secondary wave or S-wave. Shear waves propagate only in solid media, such as sediments or rock. Shear waves in the seabed can be converted to compressional waves in water at the water-seabed interface.

signature
Pressure signal generated by a source.

sound
A time-varying pressure disturbance generated by mechanical vibration waves travelling through a fluid medium such as air or water.

sound exposure
Time integral of squared, instantaneous frequency-weighted sound pressure over a stated time interval or event. Unit: pascal-squared second (Pa^2·s). Symbol: *E* (ANSI S1.1-1994 R1999).

sound exposure level (SEL)
A measure of the total sound energy in one or more pulses. Unit: dB re 1 µPa^2·s.

sound field
Region containing sound waves (ANSI S1.1-1994 R1999).

sound intensity
Sound energy flowing through a unit area perpendicular to the direction of propagation per unit time.

sound pressure level (SPL)
The decibel ratio of the time-mean-square sound pressure, in a stated frequency band, to the square of the reference sound pressure (ANSI S1.1-1994 R1999). Unit: decibel (dB). Symbol: L_p.

For sound in water, the reference sound pressure is one micropascal (p_o = 1 µPa) and the unit for SPL is dB re 1 µPa:

$$L_P = 10\log_{10}\left(p^2 / p_o^2\right) = 20\log_{10}\left(p / p_o\right)$$

Unless otherwise stated, SPL refers to the root-mean-square sound pressure level (rms SPL).

source level (SL)

The sound pressure level measured 1 metre from a point-like source that radiates the same total amount of sound power as the actual source. Unit: dB re 1 µPa @ 1 m.

transmission loss (TL)
The decibel reduction in sound level that results from sound spreading away from an acoustic source, subject to the influence of the surrounding environment. Also referred to as propagation loss.

zero-to-peak SPL
See peak SPL.

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Appendix A. Sound Speed Profiles for Modeled Sites

Figure A-1 and Figure A-2 show the August and December SSPs for all modeled sites.

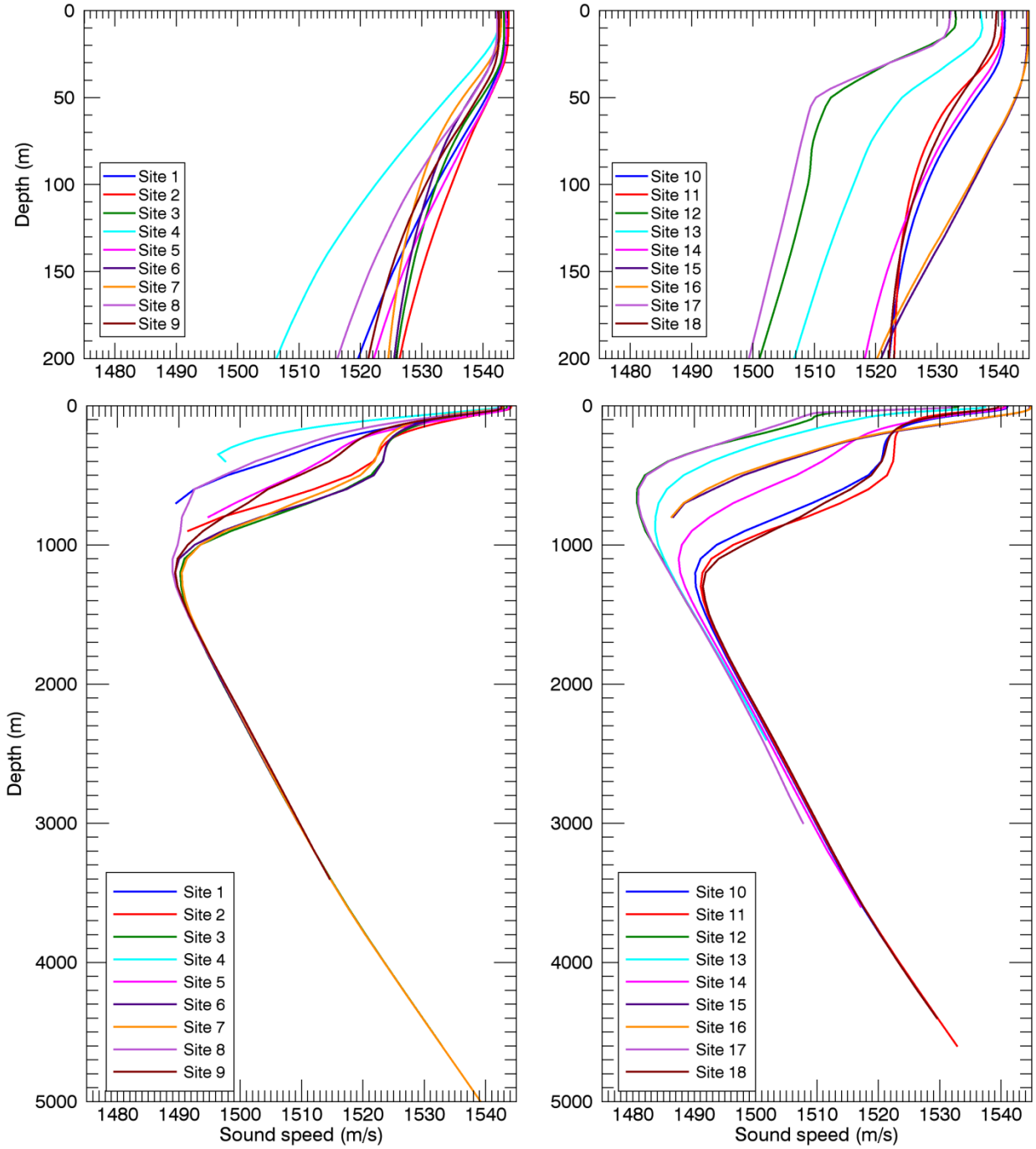

Figure A-1. Plots of representative August sound speed profiles for the acoustic calculation areas surrounding modeled sites 1–18. The upper panels presented the SSPs for the top 200 m water depth. The SSPs were obtained based on GDEM data (Carnes 2009).

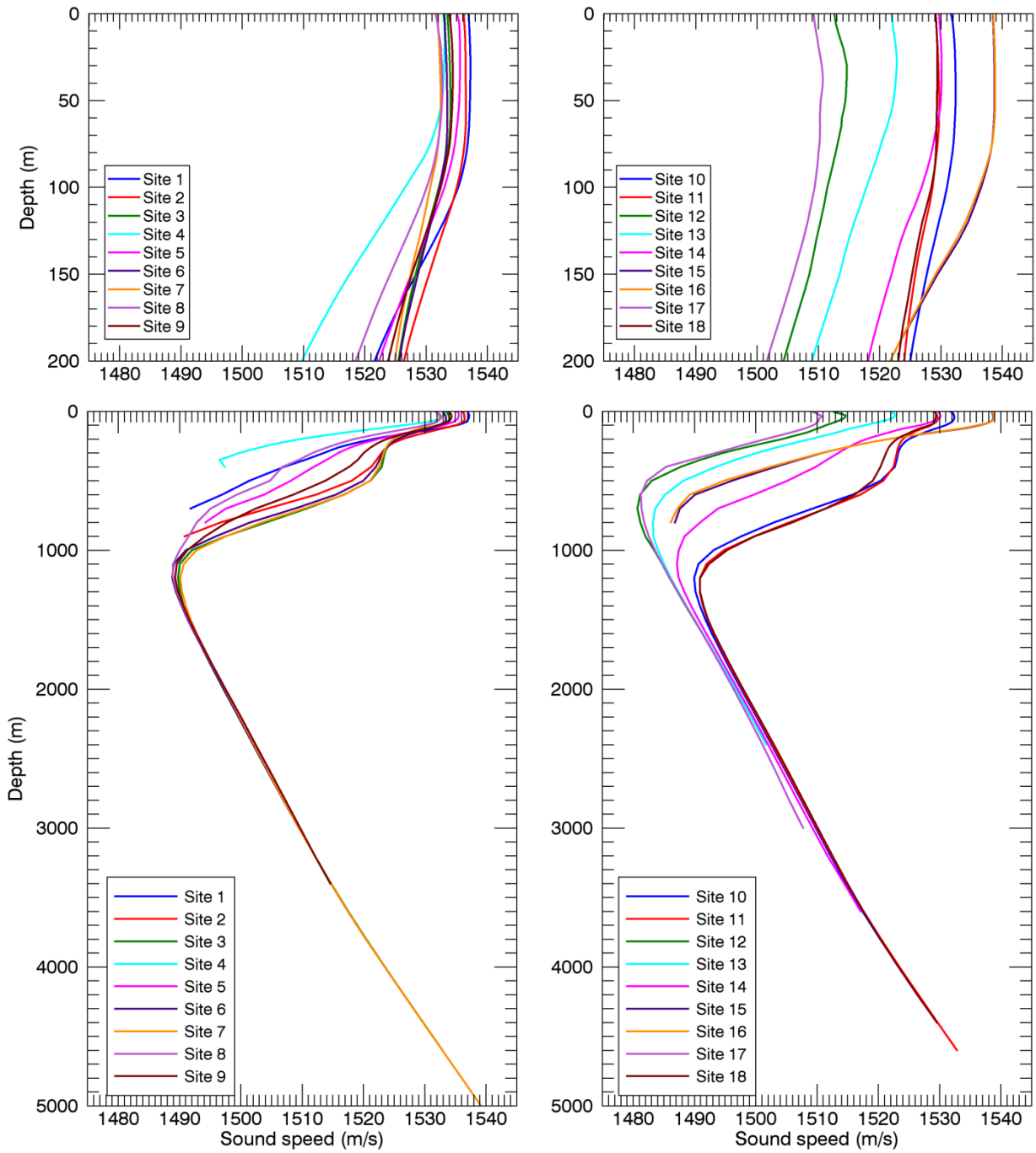

Figure A-2. Plots of representative December sound speed profiles for the acoustic calculation areas surrounding modeled sites 1–18. The upper panels presented the SSPs for the top 200 m water depth. The SSPs were obtained based on GDEM data (Carnes 2009).

Appendix B. rms SPL Contour Maps for Modeled sites

Predicted isopleth maps of SPLs are shown in Figure B-1 to Figure B-5.The map for survey line 2 is in Section 5.2.

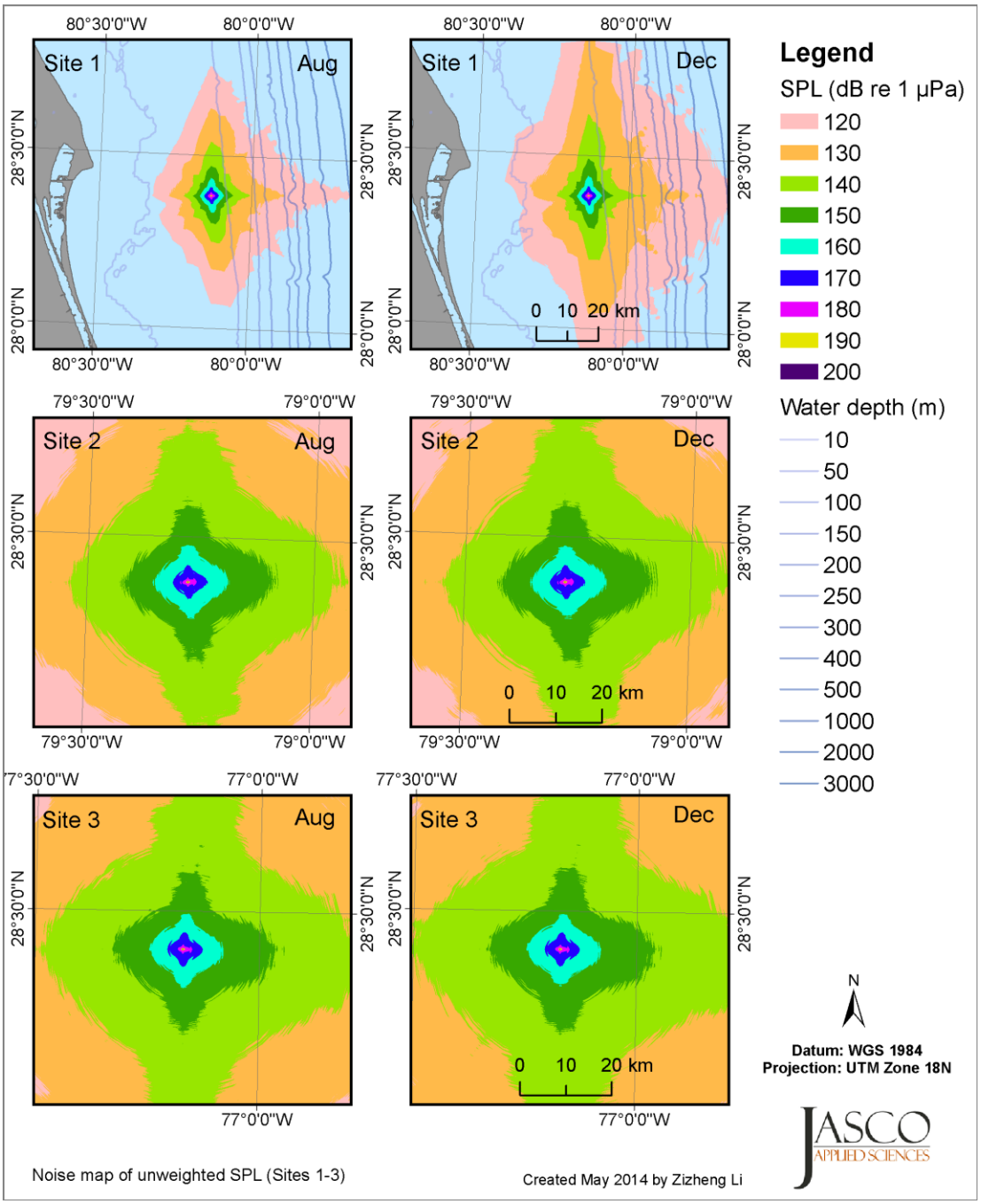

Figure B-1. Contours of rms SPL (dB re 1 μPa) produced by the 6420 in^3 airgun array at sites 1-3; August (left) and December (right). Tow directions are 88°, 88°, and 93°. The modeled site numbers are on the top left of each panel.

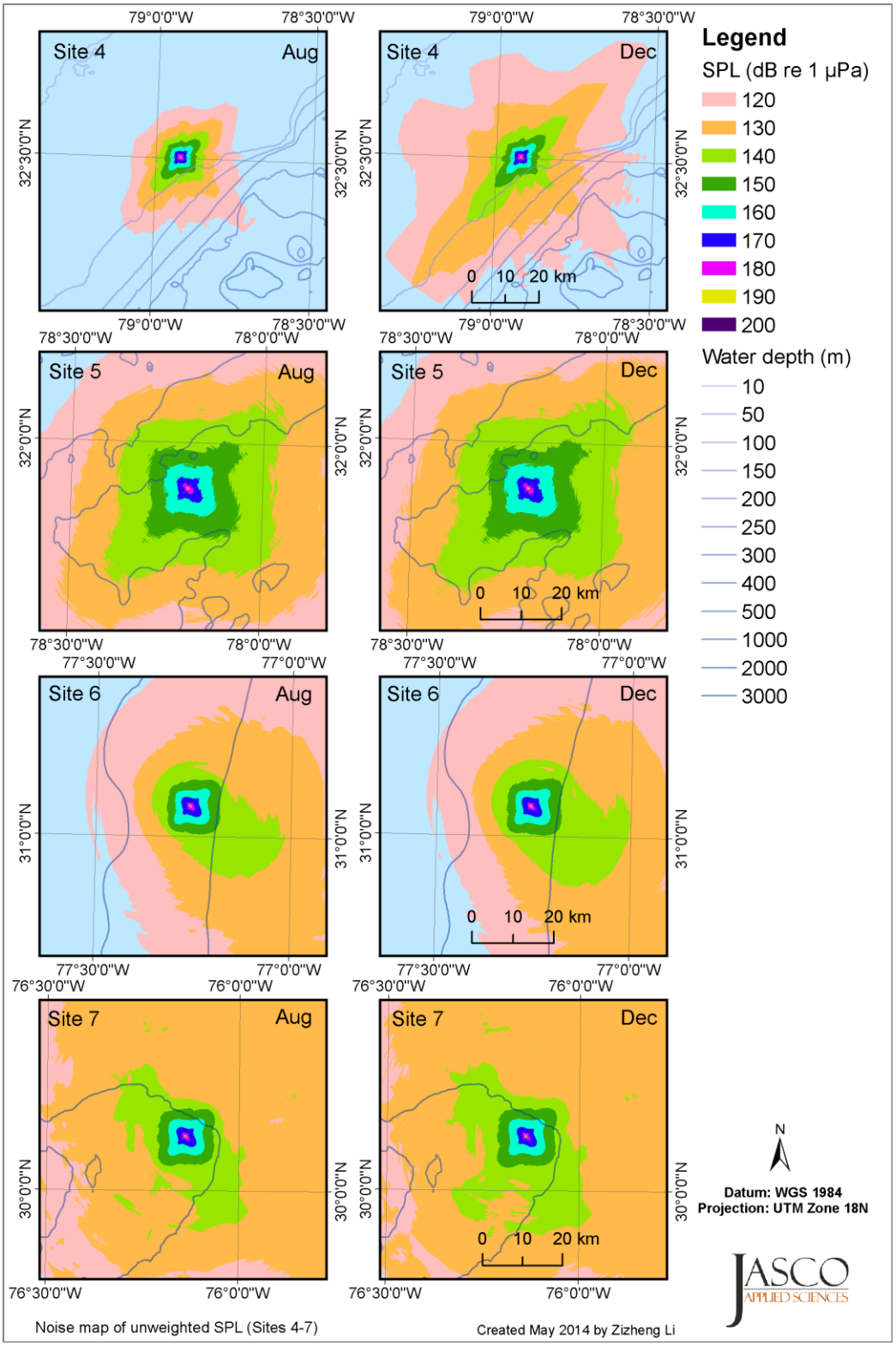

Figure B-2. Contours of rms SPL (dB re 1 µPa) produced by the 6420 in^3 airgun array at sites 4-7; August (left) and December (right). The sound speed profiles are for August (left) and December (right). Tow direction is 135°. The modeled site numbers are on the top left of each panel.

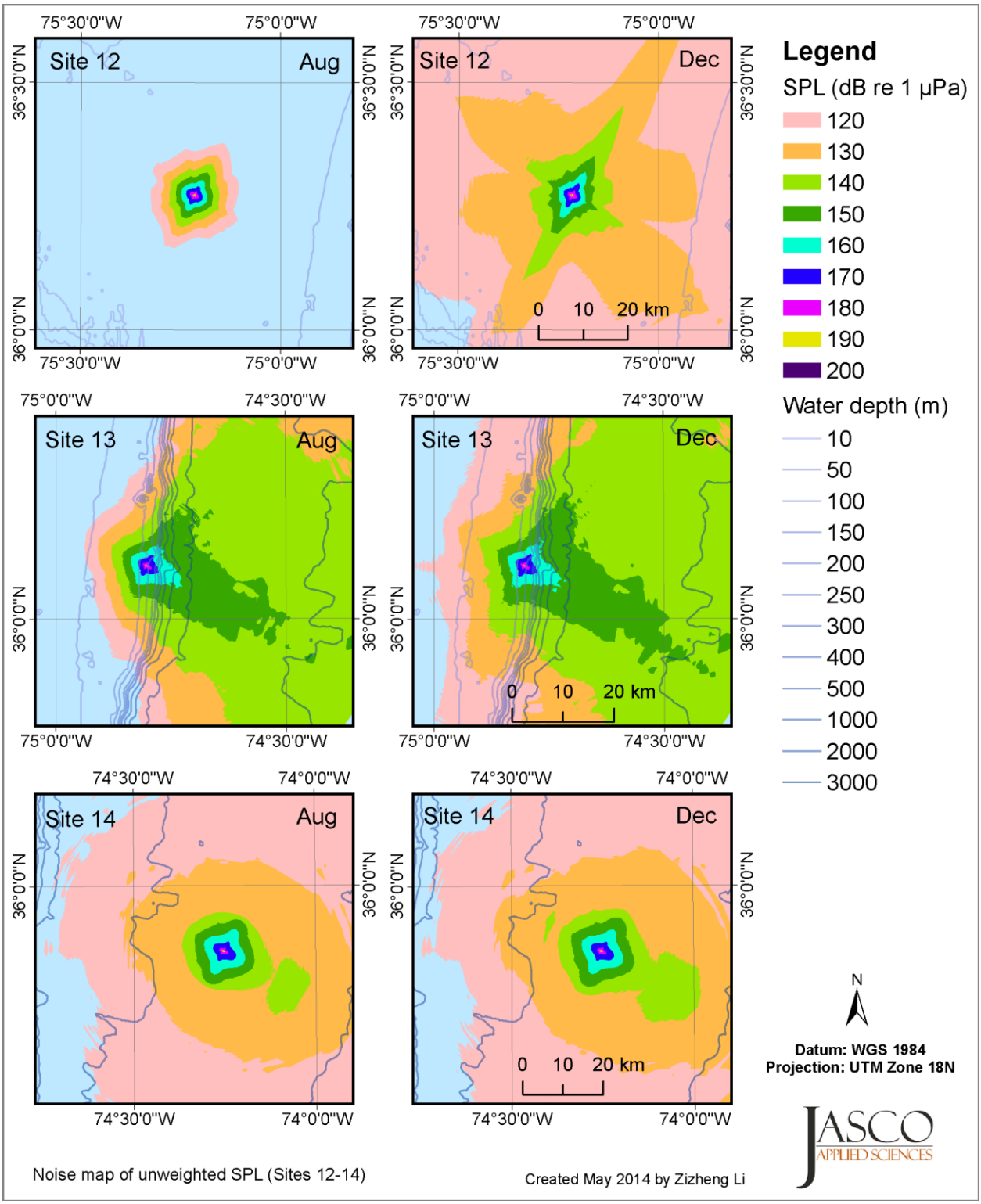

Figure B-3. Contours of rms SPL (dB re 1 µPa) produced by the 6420 in^3 airgun array at sites 12-14; August (left) and December (right). Tow direction is 118°. The modeled site numbers are on the top left of each panel.

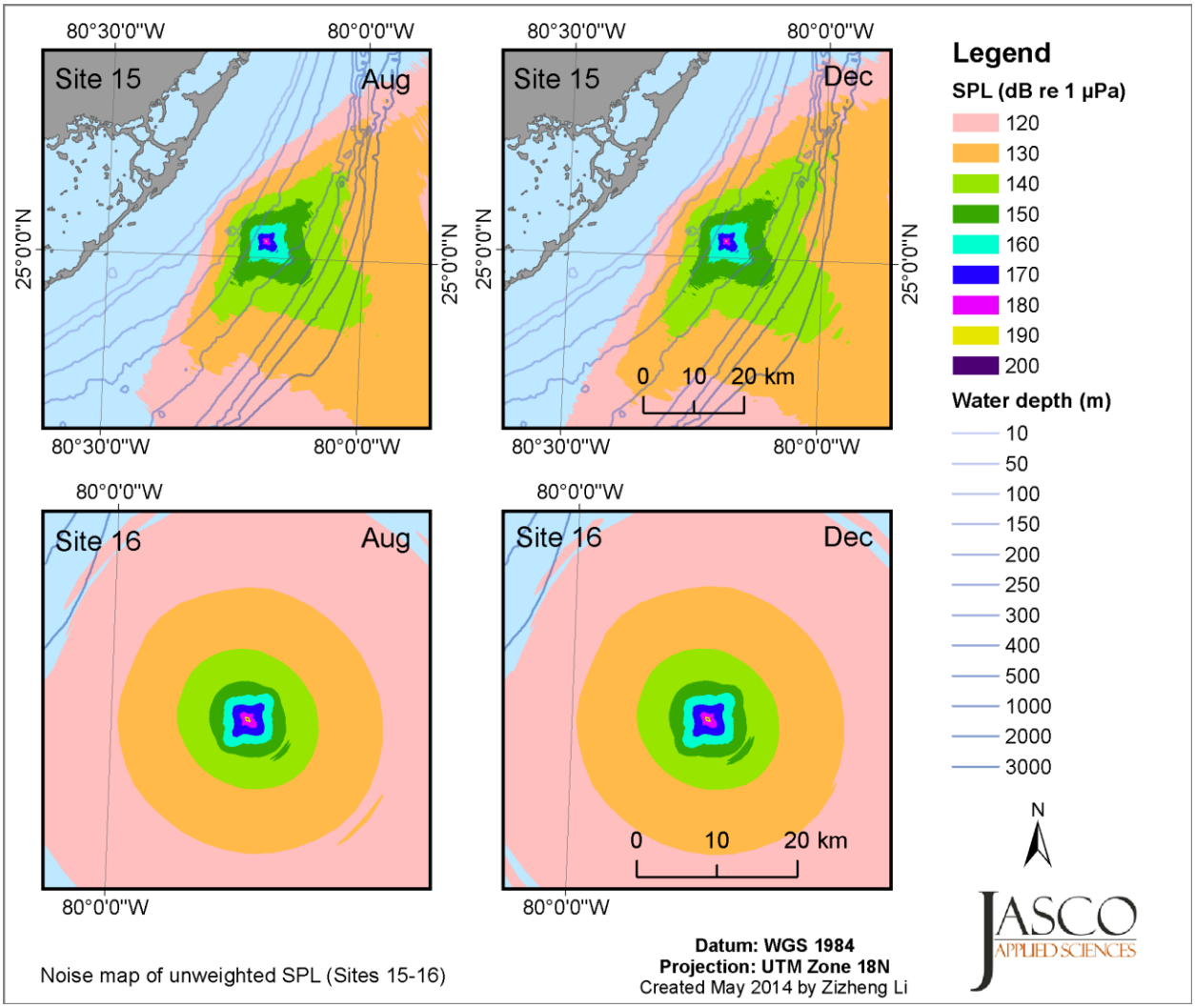

Figure B-4. Contours of rms SPL (dB re 1 µPa) produced by the 6420 in^3 airgun array at sites 15-16; August (left) and December (right). Tow direction is 133°. The modeled site numbers are on the top left of each panel.

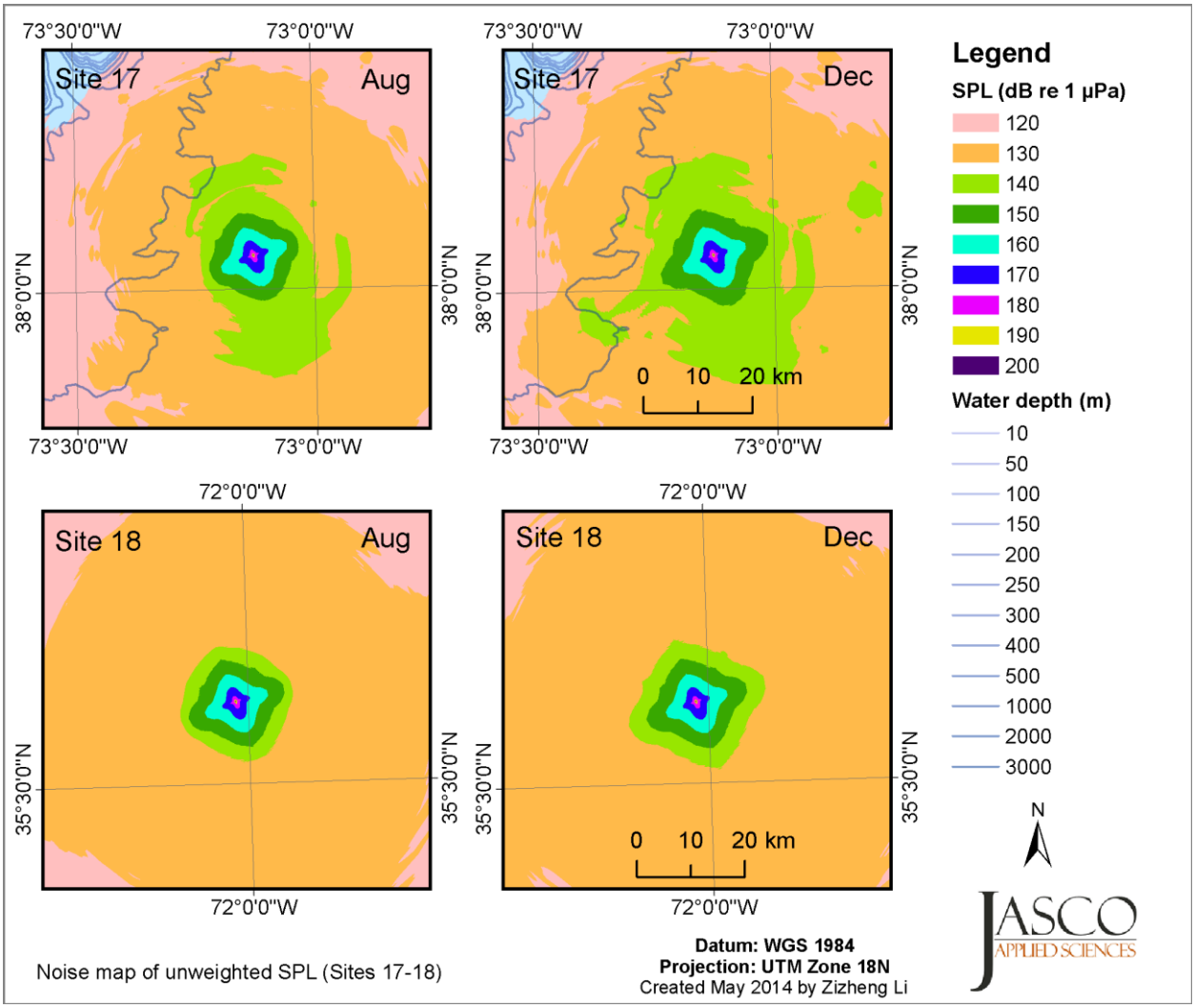

Figure B-5. Contours of rms SPL (dB re 1 µPa) produced by the 6420 in^3 airgun array at sites 17-18; August (left) and December (right). Tow directions are 158° and 160°. The modeled site numbers are on the top left of each panel.

APPENDIX B: ACOUSTIC INTEGRATION MODEL (AIM) METHODS

APPENDIX B
ACOUSTIC INTEGRATION MODEL (AIM) METHODS

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TABLE OF CONTENTS

APPENDIX B: ACOUSTIC INTEGRATION MODEL (AIM) 144

1. Rationale 144
2. Introduction to AIM 146
3. Specific Modeling Methods for the Proposed GXT Seismic Surveys 146
4. Data Convolution to Create Animat Exposure Histories 150
5. Simulation of Monitoring and Mitigation 151
6. Numbers of Mammals Exposed 151
7. Summary 155
8. Literature Cited 155

TABLE OF FIGURES

Figure 1. Illustration of pressure-based exposure or "take" methodology (not to scale). Levels are in single-pulse RMS Sound Pressure Levels (SPL), averaged over pulse duration, in dB re 1 μPa_{rms}. 145

Figure 2. An example sound history of one simulated individual that was close to the seismic vessel at its closest point of approach, showing the received sound levels (dB re 1 μPa_{rms}) as a function of time (blue points). The SEL function is shown in red; it accumulates received energy with time and reaches its maximum level shortly after the maximum single exposure (~25 hours into the simulation). 145

Figure 3. Proposed ION GeoVentures survey lines 147

Figure 4. Modeled Survey Lines. Each Line or Line Segment is individually labeled 148

Figure 5. The population of an AIM simulation is illustrated. In the left figure the inshore portion of line ML8A is shown as a white line, with the source vessel moving offshore. The yellow box illustrates the one-degree buffer around the source track that will be populated with animats. The figure on the right shows the simulation populated with common dolphins, which are represented with red diamonds. The animats are required to remain in water deeper than ten meters, and to remain within the yellow box. 149

TABLE OF TABLES

Table 1. Durations of simulation for each modeling line segment. 151

Table 2. Extent of Proposed Seismic Lines. 153

Table 3. Summary of numbers of predicted regulatory exposures (Takes) for each month. Note that these estimated are calculated as if the entire survey is completely run within each season. The values for the Southall et al. (2007) criterion (SEL Level A) were zero for all species in both months. 154

ACOUSTIC INTEGRATION MODEL (AIM) METHODS

1. Rationale

The overall goal of this modeling effort was to predict the number of animals at each of the modeling locations that would be exposed to sound levels in excess of regulatory thresholds.

Based on the U.S. MMPA, two different categories of "taking" or incidental harassment are recognized: "Level A" takes, involving injury, and "Level B" takes, involving temporary disturbance. In predicting the possible occurrence of Level A takes, two different exposure criteria were used, one based on the maximum root mean square (rms[1]) sound pressure level (SPL) received by the mammal, and the other based on the accumulated acoustic energy (sound exposure level or SEL) received by the animal. The former (pressure) criteria are the precautionary criteria that have been recognized by NMFS for several years, and apply to the strongest single pulse received by the animal. The latter (cumulative energy exposure) criteria are those proposed by the noise criteria group (Southall et al. 2007), and apply to the total acoustic energy received from the airgun array over an extended period of time. Draft criteria have been proposed by NMFS for permanent threshold shift (PTS) and temporary threshold shift (TTS), but as these are not formal guidance at this point, they were not implemented (NOAA, 2013). The NOAA draft criteria are similar to Southall et al. (2007) criteria, which were used to estimate the potential impacts from geological and geophysical operations in the Atlantic Programmatic EIS (BOEM, 2014). No draft acoustic criteria for behavioral changes have been proposed by NOAA. No pinnipeds are expected in the survey areas, so the criteria employed here are for cetaceans only, as follows:

Level A: single-pulse SPL of 180 dB re 1 μPa_{rms} and cumulative SEL of 198 dB re 1 $\mu Pa^2 \cdot s$

Level B: single-pulse SPL of 160 dB re 1 μPa_{rms}

Implementation of the SPL criteria is best demonstrated graphically (Figure 1). A sound source is surrounded by a zone of high received sound level (orange) and, generally at greater distances, a zone with lower received sound level (yellow). If the boundary between the orange and yellow areas is the distance where single-pulse SPL is 180 dB re 1 μPa_{rms}, and the outer edge of the yellow zone is the distance where SPL is 160 dB re 1 μPa_{rms}, then the orange zone corresponds to Level A exposure, and the yellow represents Level B exposure. Three examples of theoretical marine mammal tracks are shown, depicting the *relative* motion of the mammal and the sound source *as the source passes the mammal*. The top track in Figure 1 passes outside the yellow zone and does not represent either a Level B or a Level A exposure. The second track passes through the yellow zone only, and represents a Level B exposure. The bottom-most track first enters the yellow zone and then continues into the orange zone; that animal would be reported as a Level A exposure.

The accumulation of sound energy over multiple exposures for an individual mammal is illustrated in Figure 2. The individual SPL exposure values for that mammal are plotted as a function of time as blue dots. The SEL curve (in red) shows the accumulation of sound energy over time.

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

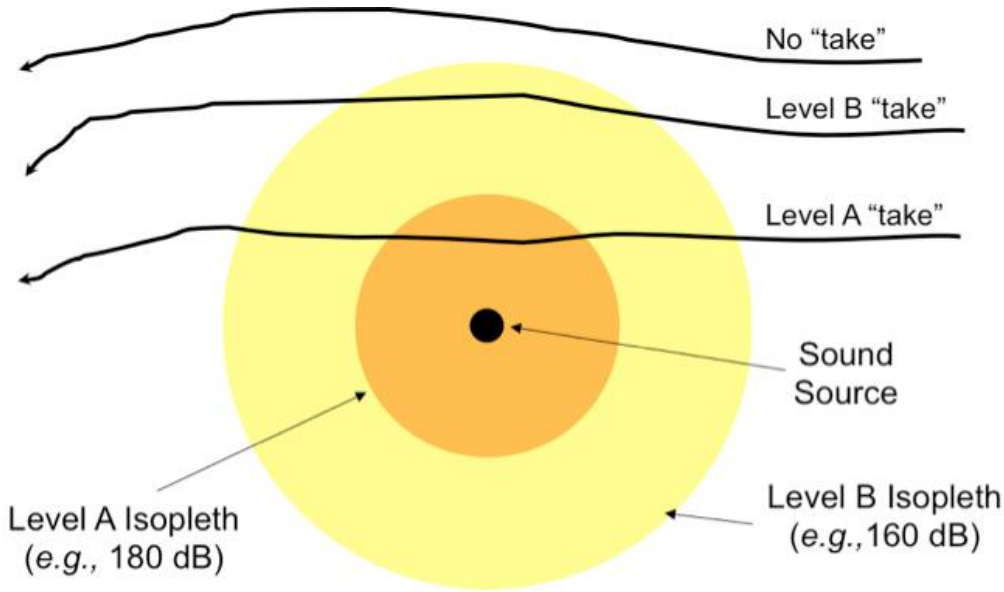

Figure 1. Illustration of pressure-based exposure or "take" methodology (not to scale). Levels are in single-pulse RMS Sound Pressure Levels (SPL), averaged over pulse duration, in dB re 1 μPa_{rms}.

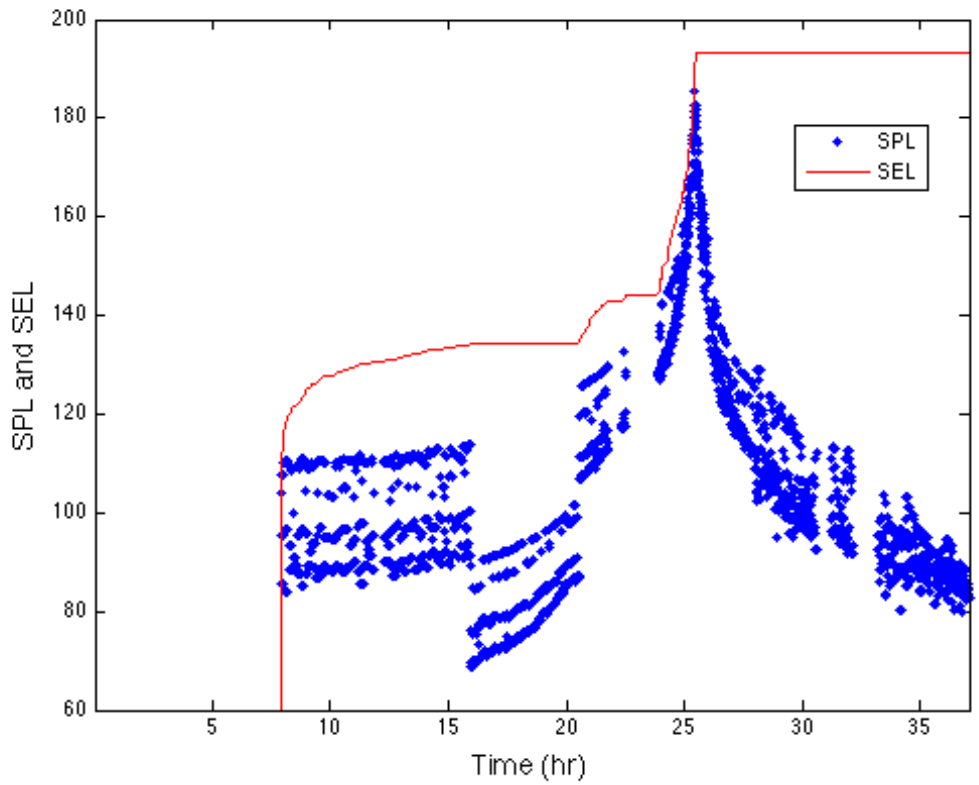

Figure 2. An example sound history of one simulated individual that was close to the seismic vessel at its closest point of approach, showing the received sound levels (dB re 1 μPa_{rms}) as a function of time (blue points). The SEL function is shown in red; it accumulates received energy with time and reaches its maximum level shortly after the maximum single exposure (~25 hours into the simulation).

2. Introduction to AIM

To estimate the numbers of marine mammals that could receive sound in excess of the SPL threshold for Level B incidental harassment and the SPL and SEL thresholds for Level A incidental harassment during the proposed seismic survey, the Acoustic Integration Model (AIM) was applied (Frankel et al. 2002). AIM is a Monte Carlo-based statistical model, strongly based on two earlier models: a whale movement and tracking model developed for the census of the bowhead whale (Ellison et al. 1987), and an underwater acoustic back-scattering model for a moving sound source in an under-ice Arctic environment (Bishop et al. 1987). Because the exact positions of sound sources and animals (sound receivers for the purpose of this analysis) are not known in advance for proposed activities, multiple runs of realistic predictions are used to provide statistical validity to the simulated scenarios. The movement and other behavior patterns of sources and receivers are modeled based on measured field data, and these patterns are incorporated into the model. Each source and/or receiver is modeled using the "animat" concept, where each animat has variables that control its speed and direction in three dimensions. The source also has variables describing its source operation over time, i.e., source level, signal duration, and pulse interval. Thus, it is possible to recreate the type of diving and movement pattern that an animal shows in the real world. Furthermore, the movement of the animat can be programmed to respond to environmental factors, such as water depth and sound level (this latter feature was not used in this analysis). These responses to the environment are entitled 'aversions'. There are a number of potential aversion variables that can be used to build an animat's behavioral pattern. In this way, species that normally inhabit specific environments can be constrained in the model to stay within that habitat.

Once the behavior of the animats has been programmed, the model is run. The run consists of a user-specified number of incremental steps forward in time. For each time step, each animat is moved according to the rules describing its behavior. For each time step of the model run, the received sound level values at each receiver (i.e., marine mammal) animat are calculated. For this analysis, AIM predicts the movement patterns of the animats, and the received sound levels are calculated separately, using the acoustic propagation predictions provided by MONM, as described in Appendix A, § 4.2.

At the end of each time step, each animat evaluates its environment including its 3-D location, the time, and received sound level (if present). If an environmental variable has exceeded the user-specified boundary value (e.g., water too shallow), then the animat will alter its course to react to the environment.

3. Specific Modeling Methods for the Proposed ION GeoVentures Seismic Survey

ION GeoVentures proposes to conduct seismic survey along six lines roughly parallel to and 13 lines roughly perpendicular to the east coast of the United States (Figure 3). A number of these lines are quite similar to each other in terms of direction and location. Therefore, a reduced number of modeling lines—five alongshore and five perpendicular to shore—were created to represent all of the proposed survey lines (Figure. 4). Most of the modeled lines were broken into two segments that correspond to the boundaries of the acoustic modeling and species density regions (see § VI of the IHA application; also BOEM 2014). In particular, the five modeled lines perpendicular to the shoreline (ML4–ML8) were broken into 'A' and 'B' segments that correspond to the coastal survey areas and the offshore survey area. Also, the two northern inshore modeled lines (ML1 and ML2) that parallel the coastline were broken into 'A' and 'B' segments that correspond to the southern coastal survey area and mid-Atlantic survey area, respectively. The line paralleling Florida's coast (ML12) was also broken into two modeling segments (A and B). The most offshore of the modeled lines parallel to the coast (ML3) is not divided, as it is entirely

within the offshore survey area. This process resulted in a total of 17 modeling line segments, each contained within one of the survey areas. Modeling lines ML1 and ML2 were further subdivided within each coastal survey area into two or three subsegments (ML1A1, ML1A2, etc.) to simplify the modeling into straight line segments. The modeling line segments that were assigned to each seismic line are shown in "Section 6. Numbers of Mammals Exposed". After models were run for each line segment and subsegment, the results from all segments in each of the survey areas were scaled to reflect the actual length of proposed seismic lines and then combined.

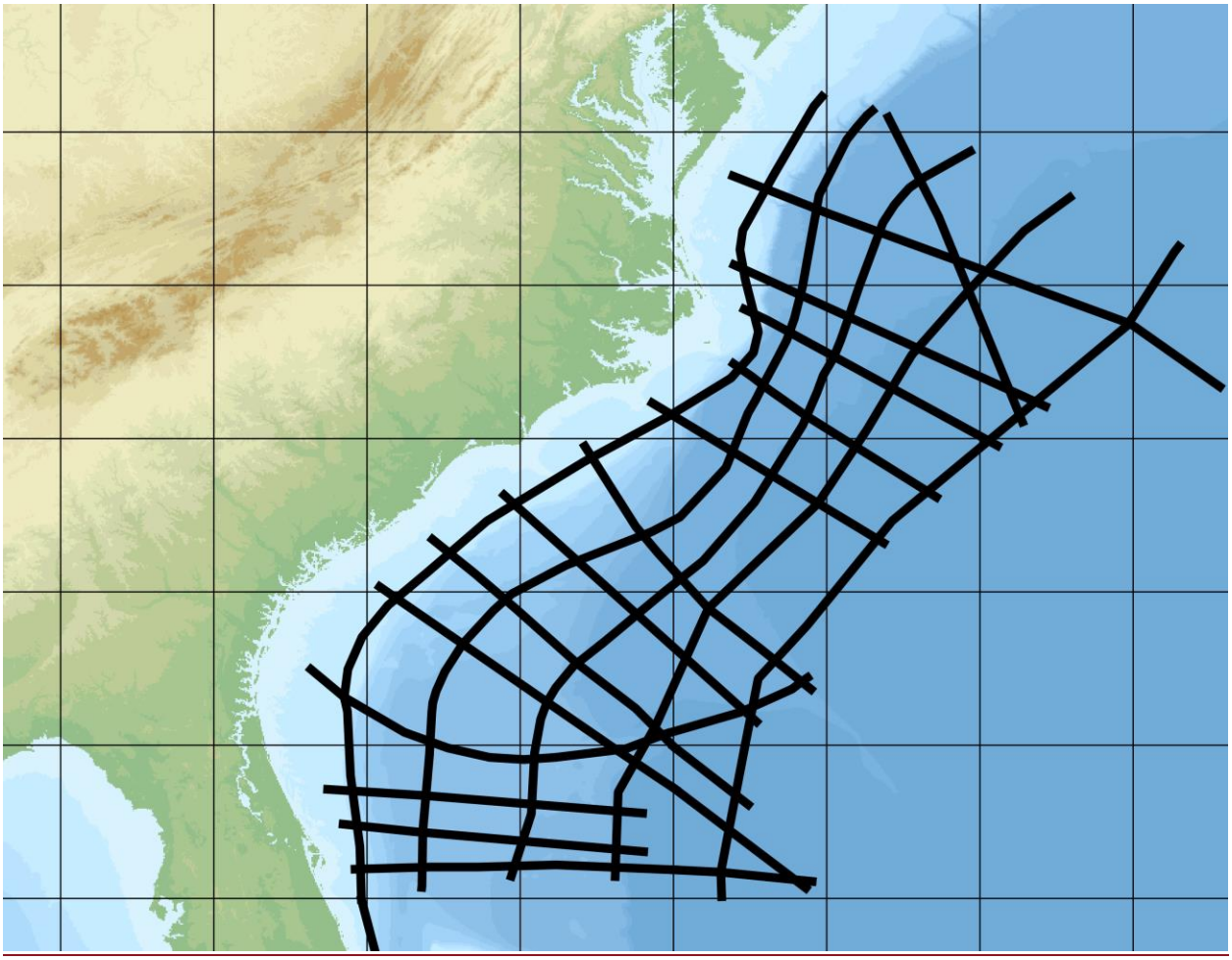

Figure 3. Proposed ION GeoVentures survey lines

The next step in the modeling procedure was to assign species- or group-specific behavioral values to each AIM animat. Behavioral values that were used in modeling animal movement were dive depth, surfacing and dive durations, swimming speed, and course change. A minimum and maximum value for each of these parameters was specified. The MAI behavioral database (Frankel and Vigness-Raposa 2014), updated with a review of current research, provided these values. For each species or species group, these data were used to simulate movements and dive characteristics of individual animats relative to the track of the simulated seismic survey vessel. The data available for some individual

species were sparse. In those cases, species were combined into phylogenetically or ecologically similar groups (e.g., all dolphins of the genus *Stenella* were modeled as a single category of *Stenella* animats).

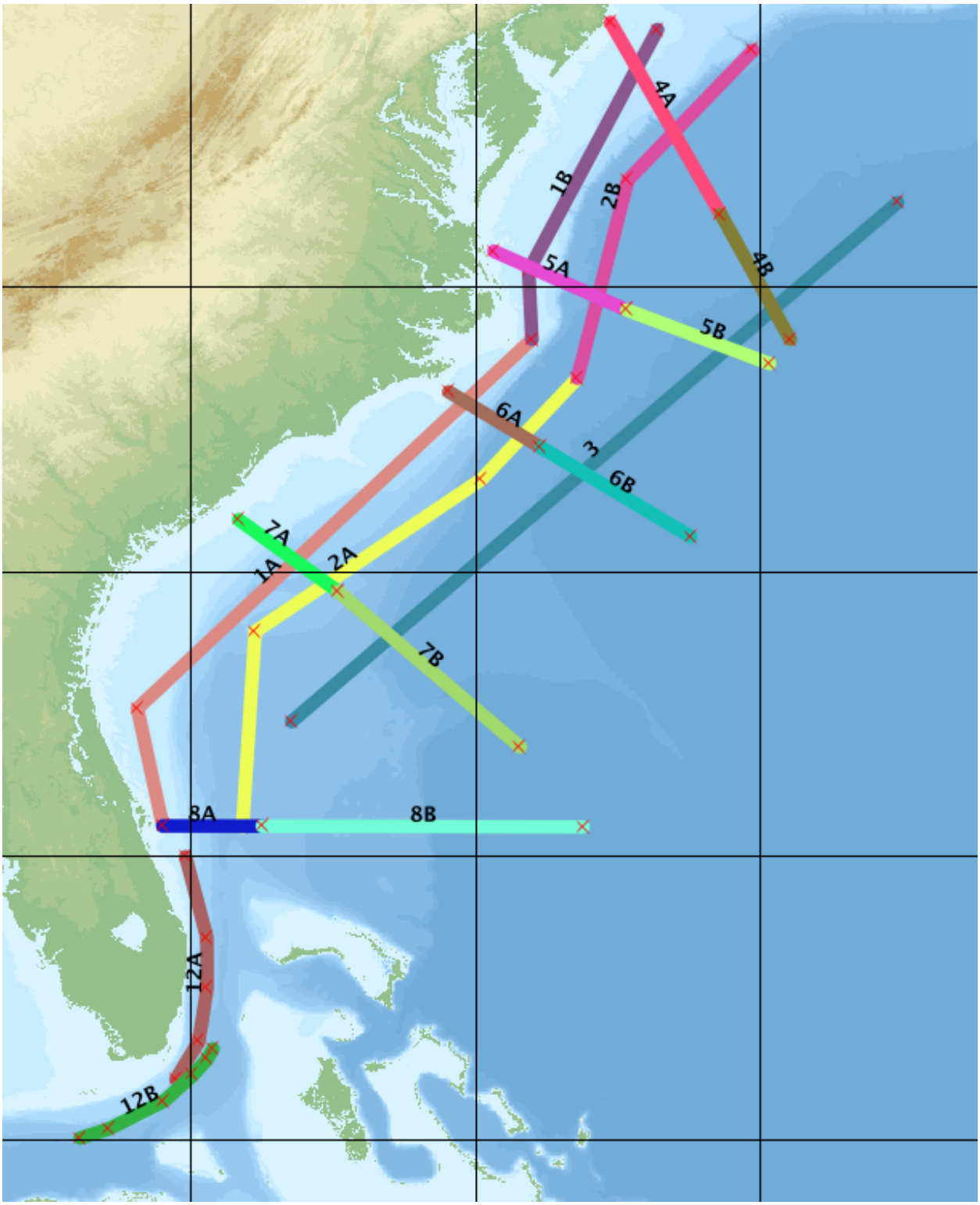

Figure 4. Modeled Survey Lines. Each Line or Line Segment is individually labeled

After the animats for a given species or species-group and for each modeling line were created, they were randomly distributed over the simulation area, which was centered on the seismic vessel track and delineated by four boundaries, composed of a combination of latitude and longitude lines, and in some cases by shoreline (Figure. 5). These boundaries extend at least 1 degree of latitude or longitude beyond the extent of the survey vessel track to insure an adequate number of animats in all directions. Simulations typically had 1000–10,000 animats representing each species or species group. A variable number of animats was modeled because of the variable length of the tracks and the varied habitat of some species. In most cases, the simulated density of animats was higher than the density of animals in the real environment. This "over-population" allowed the calculation of smoother distribution tails, and in the final analysis all results were normalized back to the actual estimated density for the species or group in question. This was done based on the ratio of the real densities (Table 1), from § VI of the IHA Application, to the animat densities. During the AIM modeling, animats were programmed to remain within the simulation area boundaries. This behavior was incorporated to prevent the animats from diffusing out of the simulation, the result of which, if allowed, would be a systematic decrease in animat density over time. Thus, the simulations modeled the animals as a closed population with a high residency factor. This approach is clearly conservative in terms of allowing for more prolonged exposures than would be expected for actual animals with a lower residency factor.

The duration of each simulation was determined by the length of the vessel track in that area, divided by the assumed survey vessel speed of 8 km/h (~4 knots). The duration of each simulation ranged from 1025 to 8475 min (Table 2). The vessel speed was based on the typical speed at which seismic survey vessels operate while conducting seismic operations.

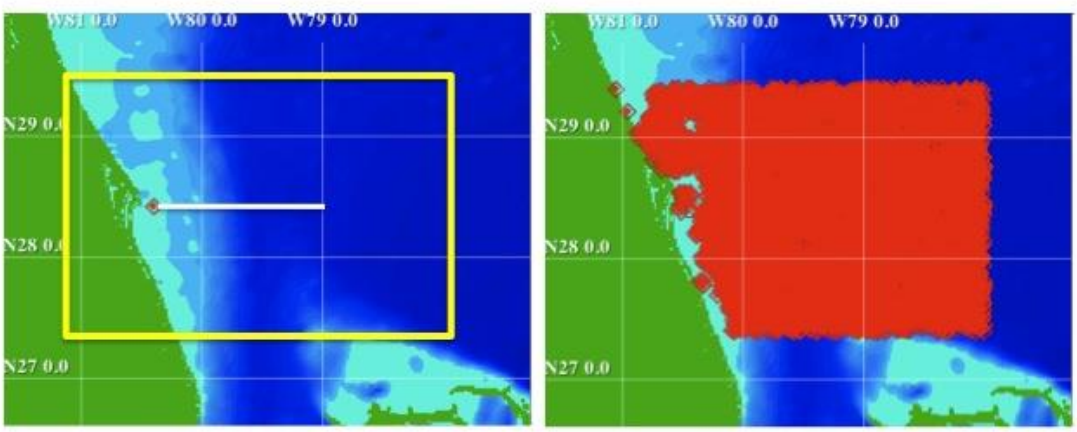

Figure 5. The population of an AIM simulation is illustrated. In the left figure the inshore portion of line ML8A is shown as a white line, with the source vessel moving offshore. The yellow box illustrates the one-degree buffer around the source track that will be populated with animats. The figure on the right shows the simulation populated with common dolphins, which are represented with red diamonds. The animats are required to remain in water deeper than ten meters, and to remain within the yellow box.

Table 1: Marine Mammal Density Estimates. Summer values are in regions 11-14. Fall values are in regions (15-21).

	Animals/km^2										
	Summer				Fall						
BOEM (2014) Modeling Region	11	12	13	14	15	16	17	18	19	20	21
Mysticetes											
Minke whale	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003
Sei whale	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003
Bryde's whale	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003
Blue whale	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003
Fin whale	0.00003	0.00003	0.00015	0.00003	0.00003	0.00015	0.00003	0.00003	0.00003	0.00006	0.00003
North Atlantic right whale	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00017	0.00003
Humpback whale	0.00000	0.00000	0.00000	0.00000	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003
Odontocetes											
Common dolphin	0.01595	0.01595	0.05271	0.05271	0.01595	0.05580	0.01595	0.01595	0.01595	0.05271	0.01595
Pygmy killer whale	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003
Short-finned pilot whale	0.00035	0.01536	0.02665	0.00863	0.01536	0.00292	0.00070	0.02446	0.02863	0.00041	0.00050
Long-finned pilot whale	0.00012	0.00478	0.00382	0.00152	0.00513	0.00096	0.00023	0.00566	0.00274	0.00003	0.00003
Risso's dolphin	0.00017	0.02566	0.03236	0.01303	0.00035	0.02572	0.00026	0.00671	0.02630	0.00688	0.01303
Northern bottlenose whale	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003
Pygmy sperm whale	0.00009	0.00009	0.00009	0.00009	0.00009	0.00009	0.00009	0.00009	0.00009	0.00009	0.00009
Dwarf sperm whale	0.00023	0.00023	0.00023	0.00023	0.00023	0.00023	0.00023	0.00023	0.00023	0.00023	0.00023
Atlantic white-sided dolphin	0.00015	0.00015	0.00009	0.00009	0.00015	0.00015	0.00015	0.00012	0.00006	0.00015	0.00003
Fraser's dolphin	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003
Sowerby's beaked whale	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003
Blainville's beaked whale	0.00000	0.00061	0.00041	0.00000	0.00061	0.00082	0.00000	0.00061	0.00082	0.00000	0.00000
Gervais' beaked whale	0.00000	0.00061	0.00041	0.00000	0.00061	0.00082	0.00000	0.00061	0.00082	0.00000	0.00000
True's beaked whale	0.00000	0.00061	0.00041	0.00000	0.00061	0.00082	0.00000	0.00061	0.00082	0.00000	0.00000
Killer whale	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003
Melon-headed whale	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003
Harbor porpoise	0.00003	0.00003	0.00003	0.00003	0.00015	0.00015	0.00015	0.00012	0.00006	0.00015	0.00003
Sperm whale	0.00003	0.00534	0.00268	0.00003	0.00268	0.00536	0.00006	0.00006	0.00006	0.00003	0.00003
False killer whale	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003
Pantropical spotted dolphin	0.00650	0.00650	0.00650	0.00650	0.00650	0.00650	0.00650	0.00650	0.00650	0.00650	0.00650
Clymene dolphin	0.00309	0.00309	0.00309	0.00309	0.00309	0.00309	0.00309	0.00309	0.00309	0.00309	0.00309
Striped dolphin	0.00784	0.01609	0.06099	0.00968	0.01443	0.07749	0.00784	0.00784	0.00784	0.00784	0.00784
Atlantic spotted dolphin	0.00061	0.05452	0.05744	0.09236	0.00644	0.07198	0.00061	0.00061	0.00353	0.07782	0.05592
Spinner dolphin	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003
Rough-toothed dolphin	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015	0.00015
Bottlenose dolphin	0.00522	0.07566	0.10974	0.07997	0.00863	0.08589	0.00522	0.08248	0.09954	0.05295	0.06656
Cuvier's beaked whale	0.00003	0.00431	0.00292	0.00003	0.00431	0.00574	0.00003	0.00431	0.00574	0.00003	0.00003
Pinnipeds											
Hooded seal	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Gray seal	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Harbor seal	0.00000	0.00000	0.00000	0.00003	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

4. Data Convolution to Create Animat Exposure Histories

The AIM simulations were based on behavioral data from the species or groups in question, and created a realistic animal movement track for each animat. It was assumed that, collectively, the animat tracks derived for each simulation were a reasonable representation of the movements of the animals in the population under consideration. The relative positions of the modeled source and animats were used to create a sound pressure level history for each animat. This history was also used to create a summed sound exposure level (SEL) for each animat.

Animat positions along each of these tracks were converted to polar coordinates (range and bearing) from the sound source to the receivers, i.e., from the simulated survey vessels to the simulated animals. These data, along with the depth of the receiver, were used to extract received level estimates from the acoustic propagation modeling results provided by JASCO (see Appendix A, § 5). For each sampling time, we considered the received level predictions for the most appropriate of the acoustic modeling sites plotted in Appendix A, Figure 2. The predicted received SPL and SEL for an animat at a given bearing and distance from the simulated seismic vessel (and at a given depth) were the SPL and SEL predicted by MONM for the corresponding bearing, distance, and depth with respect to the most appropriate acoustic modeling site and season.

Table 2. Durations of simulation for each modeling line segment.

Modeling line segment	Duration of simulation(min)
Line 1A	8045
Line 1B	3870
Line 2A	6665
Line 2B	4275
Line 3	8475
Line 4A	2470
Line 4B	1600
Line 5A	1435
Line 5B	1500
Line 6A	1105
Line 6B	1800
Line 7A	1290
Line 7B	2590
Line 8A	1025
Line 8B	3310
Line 12A	2690
Line 12B	1805

5. Assessment of Uncertainty

The total uncertainty in the predicted exposure level is the product of all the possible sources of uncertainty in the modeling procedure. These can be grouped into three categories: acoustic propagation, animal behavior, and animal density. Acoustic propagation uncertainty largely results from the natural variability in sound velocity profiles, which can be precisely measured but changes rapidly. The other contribution is seafloor composition. This changes slowly, but it is difficult to measure precisely.

The movement of animats in four dimensions is a function of the underlying model and the value of the input parameters to the model. The model inputs are actually observed behavioral rates from living animals. In all cases, the inputs to AIM are a range of values (e.g. minimum and maximum dive depth). Thus the inputs are not a point value, but a range of values, from which individual values are stochastically chosen. This provides variability in the range of behavioral values used at each step of the modeling process. Relying on a range of values rather than a single point value inherently captures the natural variability found in animal behavior and more realistically simulates exposures as they will occur during the proposed activity.

Animal density in the environment is the final, and arguably the largest source of uncertainty in the exposure prediction process. Typically, this can be directly assessed as most population or density estimates also include some representation of confidence limits. These estimates can be converted into coefficients of variation (CV). The CVs for each of the species density estimates were used to produce initial confidence limits on the predicted exposure levels and the numbers of animals that exceed regulatory thresholds.

6. Numbers of Mammals Exposed

The time history of acoustic exposure of each animat at every 30 sec time step was analyzed to calculate (1) the maximum flat-weighted SPL received by each animat and (2) the maximum M-weighted SPL received by each animat. M-weighting is a filter function that is applied to the acoustic signal to

account for the differential hearing capabilities of different species groups, which includes low-frequency (LF), mid-frequency (MF), and high-frequency (HF) cetaceans (Southall et al. 2007). The M-weighted SPL values at each time step were then converted into SEL units using JASCO-provided conversions (see Appendix A, § 4.4 and § 5.1), adjusted for the difference between modeling intervals (30 sec) and airgun shot intervals (20 sec) to determine the total energy to which an animal would be exposed during the survey.

The maximum rms received SPLs and accumulated SELs were then used to predict the number of modeled animats exposed at or above the following thresholds:

1. unweighted SPL of 160 dB re 1 μPa_{rms} (the "Level B" harassment criterion recognized by NMFS);
2. unweighted SPLs of 180 dB re 1 μPa_{rms}. (The traditional "Level A" harassment criterion recognized by NMFS);
3. accumulated SELs of 198 dB re 1 $\mu Pa^2 \cdot s$ for the three individually M-weighted groups of cetaceans (the energy-based injury criterion recommended by Southall et al. 2007).

Note that the numbers exposed at this step are based upon the lengths of model lines and the modeled density of the animats. As a last step, these numbers were then scaled by the ratios of modeled line length to anticipated seismic line length (Table 3) and modeled densities to actual animal densities. Individual species density estimates were spatially and temporally variable, with density regions defined by water depths (see § XI of the IHA application) and season. To illustrate, consider an example of one simulation that had 20 predicted exposures above a threshold, of which 10 occurred in shallow water and 10 in adjacent deep water. In this example, the over-populated modeling of the two regions resulted in an overall average density of 0.1/km^2, whereas the shallow water real world density is estimated as 0.025 animals/km^2, and the adjacent deep water density as 0.01 animals/km^2. The number of animals estimated to be exposed to above-threshold levels in the real world would be $10 \times 0.025 \div 0.1 = 2.5$ in shallow water and $10 \times 0.01 \div 0.1 = 1.0$ in deep water; that is, the number of animals exposed in the density region (10) multiplied by the ratio of the real-world density (0.025 or 0.01) to the modeled density (0.1).

Table 3. Extent of Proposed Seismic Lines.

Survey Line Name	Survey line length (km)	Corresponding Modeling Line(s)
USAM1-1000	50	12B
USAM1-1100	28	12A
USAM1-1200	564	8
USAM1-1300	370	8
USAM1-1400	384	8
USAM1-1500	657	7
USAM1-1600	450	7
USAM1-1600	211	7
USAM1-1700	524	7
USAM1-1800	431	7
USAM1-1900	431	7
USAM1-2000	328	6
USAM1-2100	295	6
USAM1-2200	341	5
USAM1-2300	399	5
USAM1-2400	615	5
USAM1-2500	442	4
USAM1-5300	1439	3
USAM1-5400	1094	3
USAM1-5500	1164	2,3
USAM1-5700	1642	2,12
USAM1-6000	1688	1,12

Table 1. Summary of numbers of predicted regulatory exposures (Takes) for each month. Note that these estimated are calculated as if the entire survey is completely run within each season, that no mitigation measures are taken, such as shutdowns for cetaceans observed within the 180 dB zone, and that no animals show avoidance of the operating airgun array. The values for the Southall et al. (2007) criterion (SEL Level A) were zero for all species in both months.

	Summer		Fall	
Species	Behavioral Takes	180 dB takes	Behavioral Takes	180 dB takes
Pygmy killer whale	0.4	0.0	0.3	0.0
Melon-headed whale	0.4	0.1	0.3	0.0
False killer whale	0.6	0.1	0.5	0.1
Common dolphin	425.9	36.7	158.7	20.1
Fraser's dolphin	92.6	2.1	66.1	5.2
Risso's dolphin	232.2	32.2	143.0	15.3
North Atlantic right whale	0.0	0.0	13.3	1.7
Humpback whale	0.0	0.0	1.8	0.1
Pygmy sperm whale	7.0	0.05	5.2	0.7
Dwarf sperm whale	134.0	7.9	81.5	5.2
Minke whale	0.0	0.0	5.9	0.6
Killer whale	0.2	0.0	5.3	1.3
Short-finned pilot whale	10.0	0.8	11.7	0.8
Long-finned pilot whale	2.9	0.3	6.6	0.7
Sei whale	45.4	7.2	16.9	2.7
Bryde's whale	166.4	12.1	135.3	9.1
Blue whale	61.5	5.9	42.9	2.0
Fin whale	7.4	1.2	3.8	0.4
Northern bottlenose whale	0.6	0.1	0.6	0.1
Sowerby's beaked whale	2.1	0.3	2.4	0.3
Blainville's beaked whale	4.6	0.5	5.6	0.5
Gervais' beaked whale	6.1	0.6	6.8	0.8
True's beaked whale	16.6	2.1	19.8	2.4
Cuvier's beaked whale	31.2	3.6	24.8	1.8
Sperm whale	26.4	2.6	10.1	1.4
Harbor porpoise	4.1	1.1	6.4	1.5
Pantropical spotted dolphin	55.9	7.6	38.4	5.6
Clymene dolphin	76.4	10.0	64.6	8.1
Striped dolphin	377.0	48.6	77.9	10.7
Atlantic spotted dolphin	659.5	74.2	138.1	20.3
Spinner dolphin	596.3	80.1	374.4	57.1
Rough-toothed dolphin	1.4	0.2	18.1	5.5
Atlantic white-sided dolphin	1.2	0.2	1.1	0.1
Bottlenose dolphin	1511.7	199.9	1000.3	105.0

7. Summary

In summary, the simulation process began with the course of a seismic vessel. Animats were programmed to move like real animals in four dimensions and were placed around the vessel. The simulation measured the distance, bearing, and depth from the source to each animat twice a minute. These data and the appropriate transmission loss value from the matrix of TL values produced by MONM were then used to determine the received levels for each animat every 30 sec. The resulting dataset was a sound exposure history for each animat. Those sound histories were examined to determine how many individuals had exposures greater than various thresholds. SELs were adjusted for (1) the hearing sensitivity of the species based on m-weighting functions and (2) the difference between modeling intervals (30 sec) and airgun shot intervals (20 sec) to determine the total energy to which an animal would be exposed during the survey. Finally those numbers were scaled by the two ratios of modeling animat density : real world animal density and modeled line length : actual seismic line length.

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APPENDIX C: REVIEW OF THE EFECTS OF AIRGUN SOUNDS ON MARINE MAMMAL[3]

[3] By **Meike Holst, Valerie D. Moulton, and W. John Richardson**, with assistance (to April 2015) by others, especially Patrick Abgrall and William E. Cross, all of LGL Ltd., environmental research associates.

TABLE OF CONTENTS

1. REVIEW OF THE EFFECTS OF AIRGUN SOUNDS ON MARINE MAMMALS 159

1.1 Categories of Sound Effects 159

1.2 Hearing Abilities of Marine Mammals 159

1.2.1 Toothed Whales (Odontocetes) 160

1.2.2 Baleen Whales (Mysticetes) 161

1.2.3 Seals and Sea Lions (Pinnipeds)..... 161

1.3 Characteristics of Airgun Sounds.....162

1.4 Masking Effects of Airgun Sounds 164

1.5 Disturbance by Seismic Surveys 166

1.5.1 Baleen Whales 167

1.5.2 Toothed Whales..... 174

1.5.3 Pinnipeds 181

1.6. Hearing Impairment and Other Physical Effects of Seismic Surveys.....183

1.6.1 Temporary Threshold Shift (TTS)..... 184

1.6.2 Permanent Threshold Shift (PTS)..... 190

1.6.3 Strandings and Mortality 192

1.6.4 Non-Auditory Physiological Effects..... 194

1.7 Literature Cited.....195

1. REVIEW OF THE EFFECTS OF AIRGUN SOUNDS ON MARINE MAMMALS

The following subsections review relevant information concerning the potential effects of sound from airguns on marine mammals. Because this review is intended to be of general usefulness, it includes references to types of marine mammals that will not be found in some specific regions.

1.1 Categories of Sound Effects

The effects of sound on marine mammals are highly variable, and can be categorized as follows (adapted from Richardson et al. 1995):

1. The sound may be too weak to be heard at the location of the animal, i.e., lower than the prevailing ambient sound level, the hearing threshold of the animal at relevant frequencies, or both;
2. The sound may be audible but not strong enough to elicit any overt behavioral response, i.e., the mammal may tolerate it, either without or with some deleterious effects (e.g., masking, stress);
3. The sound may elicit behavioral reactions of variable conspicuousness and variable relevance to the well being of the animal; these can range from subtle effects on respiration or other behaviors (detectable only by statistical analysis) to active avoidance reactions;
4. Upon repeated exposure, animals may exhibit diminishing responsiveness (habituation), or disturbance effects may persist; the latter is most likely with sounds that are highly variable in characteristics, unpredictable in occurrence, and associated with situations that the animal may perceive as a threat;
5. Any man-made sound that is strong enough to be heard has the potential to reduce (mask) the ability of marine mammals to hear natural sounds at similar frequencies, including calls from conspecifics, echolocation sounds of odontocetes, and environmental sounds due to wave action or (at high latitudes) ice movement. Intermittent airgun, sonar or other activities that result in a pulse sound output may result in a strong masking effect for only a small proportion of the time, given the short duration of these pulses relative to the inter-pulse intervals. Mammal calls and other sounds are often audible during the intervals between pulses, but mild to moderate masking may occur during that time because of reverberation.
6. Very strong sounds have the potential to cause temporary or permanent reduction in hearing sensitivity, or other physical or physiological effects. Received sound levels must far exceed the animal's hearing threshold for any temporary threshold shift to occur. Received levels must be even higher for a risk of permanent hearing impairment.

1.2 Hearing Abilities of Marine Mammals

The hearing abilities of marine mammals are functions of the following (Richardson et al. 1995; Au et al. 2000):

1. Absolute hearing threshold at the frequency in question (the level of sound barely audible in the absence of ambient noise). The "best frequency" is the frequency with the lowest absolute threshold.

2. Critical ratio (the signal-to-noise ratio required to detect a sound at a specific frequency in the presence of background noise around that frequency).
3. The ability to determine sound direction at the frequencies under consideration.
4. The ability to discriminate among sounds of different frequencies and intensities.

Marine mammals rely heavily on the use of underwater sounds to communicate and to gain information about their surroundings. Experiments and monitoring studies also show that they hear and may react to many man-made sounds including sounds made during seismic exploration (Richardson et al. 1995; Gordon et al. 2004; Nowacek et al. 2007; Tyack 2008).

1.2.1 Toothed Whales (Odontocetes)

Hearing abilities of some toothed whales (odontocetes) have been studied in detail (reviewed in Chapter 8 of Richardson et al. [1995] and in Au et al. [2000]). Hearing sensitivity of several species has been determined as a function of frequency. The small to moderate-sized toothed whales whose hearing has been studied have relatively poor hearing sensitivity at frequencies below 1 kHz, but extremely good sensitivity at, and above, several kHz. There are very few data on the absolute hearing thresholds of most of the larger, deep-diving toothed whales, such as the sperm and beaked whales. However, Cook et al. (2006) found that a stranded juvenile Gervais' beaked whale showed auditory evoked potentials (AEP) from 5 kHz up to 80 kHz (the entire frequency range that was tested), with best sensitivity at 40–80 kHz. An adult Gervais' beaked whale had a similar upper cutoff frequency (80–90 kHz; Finneran et al. 2009). For a sub-adult Blainville's beaked whale, Pacini et al. (2011) reported the best hearing range to be 40 to 50 kHz.

Most of the odontocete species have been classified as belonging to the "mid-frequency" (MF) hearing group, and the MF odontocetes (collectively) have functional hearing from about 150 Hz to 160 kHz (Southall et al. 2007). However, individual species may not have quite so broad a functional frequency range. Very strong sounds at frequencies slightly outside the functional range may also be detectable. The remaining odontocetes—the porpoises, river dolphins, and members of the genera *Cephalorhynchus* and *Kogia*—are distinguished as the "high frequency" (HF) hearing group. They have functional hearing from about 200 Hz to 180 kHz (Southall et al. 2007).

Airguns produce a small proportion of their sound at mid- and high-frequencies, although at progressively lower levels with increasing frequency. In general, most of the energy in the sound pulses emitted by airgun arrays is at low frequencies; strongest spectrum levels are below 200 Hz, with considerably lower spectrum levels above 1000 Hz, and smaller amounts of energy emitted up to ~150 kHz (Goold and Fish 1998; Sodal 1999; Goold and Coates 2006; Potter et al. 2007).

The hearing range for beluga whales is ~4–150 kHz (Castellote et al. 2014), but they hear best at frequencies of ~32–100 kHz (e.g., Mooney et al. 2013); the hearing threshold increases progressively (poorer hearing) outside of this range. Beluga whales are capable of hearing seismic and vessel-generated sounds at lower frequencies, but those sounds are not within their best hearing range. Sounds need to be at or above the hearing threshold to be readily detectable. Sounds must also be at or greater than ambient noise levels in order to be detected. There are no specific hearing data for narwhals, but it is assumed that belugas and narwhals have similar hearing abilities because of their taxonomic similarity; the two are the only species in the family Monodontidae.

Despite the relatively poor sensitivity of small odontocetes at the low frequencies that contribute most of the energy in pulses of sound from airgun arrays, airgun sounds are sufficiently strong, and con-

tain sufficient mid- and high-frequency energy, that their received levels sometimes remain above the hearing thresholds of odontocetes at distances out to several tens of kilometres (Richardson and Würsig 1997). There is no evidence that most small odontocetes react to airgun pulses at such long distances. However, beluga whales do seem quite responsive at intermediate distances (10–20 km) where sound levels are well above the ambient noise level (see below).

In summary, even though odontocete hearing is relatively insensitive to the predominant low frequencies produced by airguns, sounds from airgun arrays are audible to odontocetes, sometimes to distances of 10s of kilometres.

1.2.2 Baleen Whales (Mysticetes)

The hearing abilities of baleen whales (mysticetes) have not been studied directly given the difficulties in working with such large animals. Behavioral and anatomical evidence indicates that they hear well at frequencies below 1 kHz (Richardson et al. 1995; Ketten 2000). Frankel (2005) noted that gray whales reacted to a 21–25 kHz signal from a whale-finding sonar. Some baleen whales react to pinger sounds up to 28 kHz, but not to pingers or sonars emitting sounds at 36 kHz or above (Watkins 1986). In addition, baleen whales produce sounds at frequencies up to 8 kHz and, for humpback whales, with components up to >24 kHz (Au et al. 2006). The anatomy of the baleen whale inner ear seems to be well adapted for detection of low-frequency sounds (Ketten 1991, 1992, 1994, 2000; Parks et al. 2007b). Although humpback and minke whales (Berta et al. 2009) may have some auditory sensitivity to frequencies above 22 kHz, for baleen whales as a group, the functional hearing range is thought to be about 7 Hz to 22 kHz or possibly 25 kHz; baleen whales are said to constitute the "low-frequency" (LF) hearing group (Southall et al. 2007; Scholik-Schlomer 2012). The absolute sound levels that they can detect below 1 kHz are probably limited by increasing levels of natural ambient noise at decreasing frequencies (Clark and Ellison 2004). Ambient noise levels are higher at low frequencies than at mid frequencies. At frequencies below 1 kHz, natural ambient levels tend to increase with decreasing frequency.

The hearing systems of baleen whales are undoubtedly more sensitive to low-frequency sounds than are the ears of the small toothed whales that have been studied directly (e.g., MacGillivray et al. 2014). Thus, baleen whales are likely to hear airgun pulses farther away than can small toothed whales and, at closer distances, airgun sounds may seem more prominent to baleen than to toothed whales. However, baleen whales have commonly been seen well within the distances where sound from airguns (or other sources) would be detectable and often show no overt reaction to those sounds. Behavioral responses by baleen whales to seismic pulses have been documented, but received levels of pulsed sounds necessary to elicit behavioral reactions are typically well above the minimum levels that the whales are assumed to detect (see below).

1.2.3 Seals and Sea Lions (Pinnipeds)

Underwater audiograms have been determined using behavioral study methods for four species of phocinid seals, two species of monachid seals, two species of otariids, and the walrus (reviewed in Richardson et al. 1995: 211ff; Kastak and Schusterman 1998, 1999; Kastelein et al. 2002, 2009; Reichmuth et al. 2013; Sills et al. 2014). The functional hearing range for pinnipeds in water is considered to extend from 75 Hz to 75 kHz (Southall et al. 2007), although some individual species—especially the eared seals—do not have that broad an auditory range (Richardson et al. 1995). In comparison with odontocetes, pinnipeds tend to have lower best frequencies, lower high-frequency cutoffs, better auditory sensitivity at low frequencies, and poorer sensitivity at the best frequency.

At least some of the phocid seals have better sensitivity at low frequencies (≤1 kHz) than do odontocetes. Below 30–50 kHz, the hearing thresholds of most species tested are essentially flat down to ~1 kHz, and range between 60 and 85 dB re 1 µPa. Measurements for harbor seals indicate that, below 1 kHz, their thresholds under quiet background conditions deteriorate gradually with decreasing frequency to ~75 dB re 1 µPa at 125 Hz (Kastelein et al. 2009). Recent measurements of underwater hearing for spotted seals (*Phoca largha*) show peak sensitivity of ~51 dB re 1 µPa at 25.6 kHz and good auditory sensitivity extending seven octaves (Sills et al. 2013).

For the otariid (eared) seals, the high frequency cutoff is lower than for phocinids, and sensitivity at low frequencies (e.g., 100 Hz) is poorer than for seals (harbor seal).

1.3 Characteristics of Airgun Sounds

Airguns function by venting high-pressure air into the water. The pressure signature of an individual airgun consists of a sharp rise and then fall in pressure, followed by several positive and negative pressure excursions caused by oscillation of the resulting air bubble. The sizes, arrangement, and activation times of the individual airguns in an array are designed and synchronized to suppress the pressure oscillations subsequent to the first cycle. The resulting downward-directed pulse has a duration of only 10–20 ms, with only one strong positive and one strong negative peak pressure (Caldwell and Dragoset 2000). Most energy emitted from airguns is at relatively low frequencies. For example, typical high-energy airgun arrays emit most energy at 10–120 Hz. However, the pulses contain significant energy up to 500–1000 Hz and some energy at higher frequencies (Goold and Fish 1998; Potter et al. 2007). Studies in the Gulf of Mexico have shown that the horizontally-propagating sound can contain significant energy above the frequencies that airgun arrays are designed to emit for geophysical purposes (DeRuiter et al. 2006; Madsen et al. 2006; Tyack et al. 2006a). Energy at frequencies up to 150 kHz was found in tests of single 60-in^3 and 250-in^3 airguns (Goold and Coates 2006). Nonetheless, the predominant energy is at low frequencies.

The pulsed sounds associated with seismic exploration have higher peak levels than other industrial sounds (except those from explosions) to which whales and other marine mammals are routinely exposed. The nominal source levels of the 2- to 36-airgun arrays used by Lamont-Doherty Earth Observatory (L-DEO) from the R/V *Maurice Ewing* (now retired) and R/V *Marcus G. Langseth* (36 airguns) are 236–265 dB re 1 µPa$_{p-p}$. These are the nominal source levels applicable to downward propagation. The effective source levels for horizontal propagation are lower than those for downward propagation when the source consists of numerous airguns spaced apart from one another. Explosions are the only man-made sources with effective source levels as high as (or higher than) a large array of airguns. However, high-power sonars can have source pressure levels as high as a small array of airguns, and signal duration can be longer for a sonar than for an airgun array, making the source energy levels of some sonars more comparable to those of airgun arrays.

Several important mitigating factors need to be kept in mind. (1) Airgun arrays produce intermittent sounds, involving emission of a strong sound pulse for a small fraction of a second followed by several seconds of near silence. In contrast, some other sources produce sounds with lower peak levels, but their sounds are continuous or discontinuous but continuing for longer durations than airgun pulses. (2) Airgun arrays are designed to transmit strong sounds downward through the seafloor, and the amount of sound transmitted in near-horizontal directions is considerably reduced. Nonetheless, they also emit sounds that travel horizontally toward non-geophysical target areas. (3) An airgun array is a distributed source, not a point source. The nominal source level is an estimate of the sound that would be measured

from a theoretical point source emitting the same total energy as the airgun array. That figure is useful in calculating the expected received levels in the far field, i.e., at moderate and long distances, but not in the near field. Because the airgun array is not a single point source, there is no one location within the near field (or anywhere else) where the received level is as high as the nominal source level.

The strengths of airgun pulses can be measured in different ways, and it is important to know which method is being used when interpreting or comparing quoted source or received levels. In geophysical exploration related literature, sound pressure level (SPL) is often quoted as peak-to-peak (p-p) levels, in bar-metres or (less often) dB re 1 μPa · m. The zero to peak (0-p) level for the same pulse signal is typically ~6 dB less than the p-p level. In the biological-acoustic literature, levels of received airgun pulses are often described based on the "average" or "root-mean-square" (rms) level, where the average is calculated over the duration of the pulse. The rms value for a given airgun pulse is typically ~10 dB lower than the peak level, and 16 dB lower than the peak-to-peak value (Greene 1997; McCauley et al. 1998, 2000a), depending on the extent of the averaging window used in the rms calculation. A measure that is increasingly used to characterise sound energy is the Sound Exposure Level (SEL), in dB re 1 $\mu Pa^2 \cdot s$. Because the pulses, even when stretched by propagation effects (see below), are usually <1 s in duration, the numerical value of the energy is usually lower than the rms pressure level. However, the units are different.[4] Because the level of a given pulse will differ substantially depending on which of these measures is being applied, it is important to be aware which measure is in use when interpreting or comparing any quoted sound level. For example, the U.S. National Marine Fisheries Service (NMFS) has commonly referred to rms levels when discussing levels of pulsed sounds that might "harass" marine mammals.

Seismic sound pulses received at any given point will arrive via a direct path, indirect paths that include reflection from the sea surface and bottom, and often indirect paths including segments through the bottom sediments. Sounds propagating via indirect paths travel longer distances and often arrive later than sounds arriving via a direct path. (However, sound traveling in the bottom sediments may travel faster than that in the water, and thus may, in some situations, arrive slightly earlier than the direct arrival despite traveling a greater distance.) These variations in travel time have the effect of lengthening the duration of the received pulse, or may cause two or more received pulses from a single emitted pulse. Near the source, the predominant part of an airgun pulse is ~10–20 ms in duration. In comparison, the pulse duration as received at long horizontal distances can be much greater. For example, for one airgun array operating in the Beaufort Sea, pulse duration was ~300 ms at a distance of 8 km, 500 ms at 20 km, and 850 ms at 73 km (Greene and Richardson 1988).

The rms level for a given pulse (when measured over the duration of that pulse) depends on the extent to which propagation effects have "stretched" the duration of the pulse by the time it reaches the receiver (e.g., Madsen 2005). As a result, the rms values for various received pulses are not perfectly correlated with the SEL (energy) values for the same pulses. There is increasing evidence that biological effects are more directly related to the received energy, which has resulted in a move towards using SEL

[4] The rms value for a given airgun array pulse, as measured at a horizontal distance on the order of 0.1 km to 1-10 km in the units dB re 1 μPa, usually averages 10–15 dB higher than the SEL value for the same pulse measured in dB re 1 $\mu Pa^2 \cdot s$ (e.g., Greene 1997). However, there is considerable variation, and the difference tends to be larger close to the airgun array, and less at long distances (Blackwell et al. 2007; MacGillivray and Hannay 2007a,b). In some cases, generally at longer distances, pulses are "stretched" by propagation effects to the extent that the rms and SEL values (in the respective units mentioned above) become very similar (e.g., MacGillivray and Hannay 2007a,b).

rather than SPL rms values averaged over pulse duration (Southall et al. 2007) to assess the potential effects (at least hearing impairment) of sound on marine mammals. However, there is also recent evidence that auditory effect in a given animal is not a simple function of received acoustic energy. Frequency, duration of the exposure, and occurrence of gaps within the exposure can also influence the auditory effect (Mooney et al. 2009a; Finneran and Schlundt 2010, 2011, 2013; Finneran et al. 2010a,b; Finneran 2012; Kastelein et al. 2013a).

Another important aspect of sound propagation is that received levels of low-frequency underwater sounds diminish close to the surface because of pressure-release and interference phenomena that occur at and near the surface (Urick 1983; Richardson et al. 1995; Potter et al. 2007). Paired measurements of received airgun sounds at depths of 3 vs. 9 or 18 m have shown that received levels are typically several decibels lower at 3 m (Greene and Richardson 1988). For a mammal whose auditory organs are within 0.5 or 1 m of the surface, the received level of the predominant low-frequency components of the airgun pulses would be further reduced. In deep water, the received levels at deep depths can be considerably higher than those at relatively shallow (e.g., 18 m) depths and the same horizontal distance from the airguns (Tolstoy et al. 2004a,b).

Pulses of underwater sound from open-water seismic exploration are often detected 50–100 km from the source location, even during operations in nearshore waters (Greene and Richardson 1988; Burgess and Greene 1999). At those distances, the received levels are usually low, <120 dB re 1 μPa on an approximate rms basis. However, faint seismic pulses are sometimes detectable at even greater ranges (e.g., Bowles et al. 1994; Fox et al. 2002). In fact, low-frequency airgun signals sometimes can be detected thousands of kilometres from their source. For example, sound from seismic surveys conducted offshore of Nova Scotia, the coast of western Africa, and northeast of Brazil were reported as a dominant feature of the underwater noise field recorded along the mid-Atlantic ridge (Nieukirk et al. 2004).

1.4 Masking Effects of Airgun Sounds

Masking is the obscuring of sounds of interest by interfering sounds, generally at similar frequencies. Introduced underwater sound will, through masking, reduce the effective communication distance of a marine mammal species • if the frequency of the source is close to that used as a signal by the marine mammal, and • if the anthropogenic sound is present for a significant fraction of the time (Richardson et al. 1995; Clark et al. 2009; Jensen et al. 2009; Gervaise et al. 2012; Hatch et al. 2012; Rice et al. 2014). Conversely, if little or no overlap occurs between the introduced sound and the frequencies used by the species, communication is not expected to be disrupted. Also, if the introduced sound is present only infrequently, communication is not expected to be disrupted much if at all. 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; Finneran and Branstetter 2013). The biological repercussions of a loss of communication space, to the extent that this occurs, are unknown.

The duty cycle of airguns is low; the airgun sounds are pulsed, with relatively quiet periods between pulses. In most situations, strong airgun sound will only be received for a brief period (<1 s), with these sound pulses being separated by at least several seconds of relative silence, and longer in the case of deep-penetration surveys or refraction surveys. A single airgun array would cause strong masking in only one situation: When propagation conditions are such that sound from each airgun pulse reverberates strongly and persists for much or all of the interval up to the next airgun pulse (e.g., Simard et al. 2005; Clark and Gagnon 2006). Situations with prolonged *strong* reverberation are infrequent, in our

experience. 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, 2013; Klinck et al. 2012), and this weaker reverberation presumably reduces the detection range of calls and other natural sounds to some degree. Guerra et al. (2013) 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 to 51% when a seismic survey was operating 450–2800 km away. Based on preliminary modelling, Wittekind et al. (2013) reported that airgun sounds may reduce the communication range of blue and fin whales 2000 km from the seismic source. Nieukirk et al. (2012) and Blackwell et al. (2013) noted the potential for masking effects from seismic surveys on large whales.

Although masking effects of pulsed sounds on marine mammal calls and other natural sounds are expected to be limited, there are few specific studies on this. Some whales continue calling in the presence of seismic pulses and whale calls often can be heard between the seismic pulses (e.g., Richardson et al. 1986; McDonald et al. 1995; Greene et al. 1999a,b; Nieukirk et al. 2004, 2012; Smultea et al. 2004; Holst et al. 2005a,b, 2006, 2011; Dunn and Hernandez 2009; Broker et al. 2013; Cerchio et al. 2014). However, some of these studies found evidence of reduced calling (or at least reduced call detection rates) in the presence of seismic pulses. One recent report indicates that calling fin whales distributed in a part of the North Atlantic went silent for an extended period starting soon after the onset of a seismic survey in the area (Clark and Gagnon 2006). It is not clear from that paper whether the whales ceased calling because of masking, or whether this was a behavioral response not directly involving masking. Also, bowhead whales in the Beaufort Sea apparently decrease their calling rates in response to seismic operations, although movement out of the area also contributes to the lower call detection rate (Blackwell et al. 2013). In contrast, Di Iorio and Clark (2010) found that blue whales in the St. Lawrence Estuary *increased* their call rates during operations by a lower-energy seismic source. The sparker used during the study emitted frequencies of 30–450 Hz with a relatively low source level of 193 dB re 1 $\mu Pa_{pk\text{-}pk}$. There is some evidence that fin whale song notes recorded in the Mediterranean had lower bandwidths during periods with versus without airgun sounds (Castellote et al. 2012).

Among the odontocetes, there has been one report that sperm whales ceased calling when exposed to pulses from a very distant seismic ship (Bowles et al. 1994). However, more recent studies of sperm whales found that they continued calling in the presence of seismic pulses (Madsen et al. 2002; Tyack et al. 2003; Smultea et al. 2004; Holst et al. 2006, 2011; Jochens et al. 2008; Nieukirk et al. 2012). Madsen et al. (2006) noted that airgun sounds would not be expected to cause significant masking of sperm whale calls given the intermittent nature of airgun pulses. (However, some limited masking would be expected due to reverberation effects, as noted above.) Dolphins and porpoises are also commonly heard calling while airguns are operating (Gordon et al. 2004; Smultea et al. 2004; Holst et al. 2005a,b, 2011; Potter et al. 2007). Masking effects of seismic pulses are expected to be negligible in the case of the smaller odontocetes, given the intermittent nature of seismic pulses plus the fact that sounds important to them are predominantly at much higher frequencies than are the dominant components of airgun sounds.

Pinnipeds, sirenians and sea otters have best hearing sensitivity and/or produce most of their sounds at frequencies higher than the dominant components of airgun sound, but there is some overlap in the frequencies of the airgun pulses and the calls. However, the intermittent nature of airgun pulses presumably reduces the potential for masking.

Some cetaceans are known to increase the source levels of their calls in the presence of elevated sound levels, shift their peak frequencies in response to strong sound signals, or otherwise modify their vocal behavior in response to increased noise (Dahlheim 1987; Au 1993; reviewed in Richardson et al. 1995:233*ff*, 364*ff*; also Lesage et al. 1999; Terhune 1999; Nieukirk et al. 2005; Scheifele et al. 2005; Parks et al. 2007a, 2009, 2011, 2012; Hanser et al. 2009; Holt et al. 2009; Di Iorio and Clark 2010; McKenna 2011; Castellote et al. 2012; Melcón et al. 2012; Risch et al. 2012; Tyack and Janik 2013). It is not known how often these types of responses occur upon exposure to airgun sounds. If cetaceans exposed to airgun sounds sometimes respond by changing their vocal behavior, this adaptation, along with directional hearing and preadaptation to tolerate some masking by natural sounds (Richardson et al. 1995), would all reduce the importance of masking by seismic pulses.

1.5 Disturbance by Seismic Surveys

Disturbance includes a variety of effects, including subtle to conspicuous changes in behavior, movement, and displacement. In the terminology of the 1994 amendments to the U.S. Marine Mammal Protection Act (MMPA), seismic noise could cause "Level B" harassment of certain marine mammals. Level B harassment is defined as "...disruption of behavioral patterns, including, but not limited to, migration, breathing, nursing, breeding, feeding, or sheltering".

There has been debate regarding how substantial a change in behavior or mammal activity is required before the animal should be deemed to be "taken by Level B harassment". NMFS has stated that

> "…a simple change in a marine mammal's actions does not always rise to the level of disruption of its behavioral patterns. … If the only reaction to the [human] activity on the part of the marine mammal is within the normal repertoire of actions that are required to carry out that behavioral pattern, NMFS considers [the human] activity not to have caused a disruption of the behavioral pattern, provided the animal's reaction is not otherwise significant enough to be considered disruptive due to length or severity. Therefore, for example, a short-term change in breathing rates or a somewhat shortened or lengthened dive sequence that are within the animal's normal range and that do not have any biological significance (i.e., do no disrupt the animal's overall behavioral pattern of breathing under the circumstances), do not rise to a level requiring a small take authorization." (NMFS 2001, p. 9293).

Based on this guidance from NMFS, and on NRC (2005), simple exposure to sound, or brief reactions that do not disrupt behavioral patterns in a potentially significant manner, do not constitute harassment or "taking". In this analysis, we interpret "potentially significant" to mean in a manner that might have deleterious effects on the well-being of individual marine mammals or their populations.

Even with this guidance, there are difficulties in defining what marine mammals should be counted as "taken by harassment". Available detailed data on reactions of marine mammals to airgun sounds (and other anthropogenic sounds) are limited to relatively few species and situations (see Richardson et al. 1995; Gordon et al. 2004; Nowacek et al. 2007; Southall et al. 2007). Behavioral reactions of marine mammals to sound are difficult to predict in the absence of site- and context-specific data. Reactions to sound, if any, depend on species, state of maturity, experience, current activity, reproductive state, time of day, and many other factors (Richardson et al. 1995; Wartzok et al. 2004; Southall et al. 2007; Weilgart 2007; Ellison et al. 2012). If a marine mammal reacts 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. 2013). 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 (e.g., Lusseau and Bejder 2007; Weilgart 2007). Also, various authors have noted that some marine mammals that show no obvious avoidance or behavioral changes may still be adversely affected by sound (Brodie 1981; Richardson et al. 1995:317*ff*; Romano et al. 2004; Weilgart 2007; Wright et al. 2009, 2011). For example, some research suggests that animals in poor condition or in an already stressed state may not react as strongly to human disturbance as would more robust animals (e.g., Beale and Monaghan 2004).

Studies of the effects of seismic surveys have focused almost exclusively on the effects on individual species or related groups of species, with little scientific or regulatory attention being given to broader community-level issues. Harwood et al. (2013) emphasized the need for a framework to assess consequences of effects from underwater noise at a population level. Parente et al. (2007) suggested that the diversity of cetaceans near the Brazil coast was reduced during years with seismic surveys. However, a preliminary account of a more recent analysis suggests that the trend did not persist when additional years were considered (Britto and Silva Barreto 2009).

Given the many uncertainties in predicting the quantity and types of impacts of sound on marine mammals, it is common practice to estimate how many mammals would be present within a particular distance of human activities and/or exposed to a particular level of anthropogenic sound. In most cases, this approach likely overestimates the numbers of marine mammals that would be affected in some biologically important manner. One of the reasons for this is that the selected distances/isopleths are based on limited studies indicating that some animals exhibited short-term reactions at this distance or sound level, whereas the calculation assumes that all animals exposed to this level would react in a biologically significant manner.

The definitions of "taking" in the U.S. MMPA, and its applicability to various activities, were slightly altered in November 2003 for military and federal scientific research activities. Also, NMFS is proposing to replace current Level A and B harassment criteria with guidelines based on exposure characteristics that are specific to particular groups of mammal species and to particular sound types (NOAA 2013). Southall et al. (2007) made detailed recommendations for new science-based noise exposure criteria, and NMFS has taken at least some of those into account. The new exposure criteria have not yet been finalized (NOAA 2013); thus, for projects subject to U.S. jurisdiction, changes in procedures may be required in the near future.

The sound criteria used to estimate how many marine mammals might be disturbed to some biologically significant degree by seismic survey activities are primarily based on behavioral observations of a few species. Detailed studies have been done on humpback, gray, bowhead, and sperm whales, and on ringed seals. 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.

1.5.1 Baleen Whales

Baleen whales generally tend to avoid operating airguns, but avoidance radii are quite variable among species, locations, whale activities, oceanographic conditions affecting sound propagation, etc. (reviewed in Richardson et al. 1995; Gordon et al. 2004). Whales are often reported to show no overt reactions to pulses from large arrays of airguns at distances beyond a few kilometres, even though the airgun pulses remain well above ambient noise levels out to much longer distances. However, baleen whales exposed to strong sound pulses from airguns often react by deviating from their normal migration route and/or interrupting their feeding and moving away. Some of the major studies and reviews on this

topic are Malme et al. (1984, 1985, 1988); Richardson et al. (1986, 1995, 1999); Ljungblad et al. (1988); Richardson and Malme (1993); McCauley et al. (1998, 2000a,b); Miller et al. (1999, 2005); Gordon et al. (2004); Stone and Tasker (2006); Johnson et al. (2007); Nowacek et al. (2007); Weir (2008a); and Moulton and Holst (2010). Although baleen whales often show only slight overt responses to operating airgun arrays (Stone and Tasker 2006; Weir 2008a), strong avoidance reactions by several species of mysticetes have been observed at ranges up to 6–8 km and occasionally as far as 20–30 km from the source vessel when large arrays of airguns were used. Experiments with a single airgun showed that bowhead, humpback and gray whales all showed localized avoidance to a single airgun of 20–100 in^3 (Malme et al. 1984, 1985, 1986, 1988; Richardson et al. 1986; McCauley et al. 1998, 2000a,b).

Studies of gray, bowhead, and humpback whales have shown that seismic pulses with received levels of 160–170 dB re 1 μPa_{rms} SPL seem to cause obvious avoidance behavior in a substantial portion of the animals exposed (Richardson et al. 1995). In many areas, seismic pulses from large arrays of airguns diminish to those levels at distances ranging from 4–15 km from the source. More recent studies have shown that some species of baleen whales (bowheads and humpbacks in particular) at times show strong avoidance at received levels lower than 160–170 dB re 1 μPa_{rms} SPL. The largest avoidance radii involved migrating bowhead whales, which avoided an operating seismic vessel by 20–30 km (Miller et al. 1999; Richardson et al. 1999). In the cases of migrating bowhead (and gray) 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). Feeding bowhead whales, in contrast to migrating whales, show much smaller avoidance distances (Miller et al. 2005; Harris et al. 2007), presumably because moving away from a food concentration has greater cost to the whales than does a course deviation during migration.

The following subsections provide more details on the documented responses of particular species and groups of baleen whales to marine seismic operations.

Humpback Whale

Responses of humpback whales to seismic surveys have been studied during migration, on the summer feeding grounds, and on Angolan winter breeding grounds; there has also been discussion of effects on the Brazilian wintering grounds. McCauley et al. (1998, 2000a) studied the responses of migrating humpback whales off Western Australia to a full-scale seismic survey with a 16-airgun 2678-in^3 array, and to a single 20 in^3 airgun with a (horizontal) source level of 227 dB re 1 $\mu Pa \cdot m_{p\text{-}p}$ SPL. They found that the overall distribution of humpbacks migrating through their study area was unaffected by the full-scale seismic program, although localized displacement varied with pod composition, behavior, and received sound levels. Observations were made from the seismic vessel, from which the maximum viewing distance was listed as 14 km. Avoidance reactions (course and speed changes) began at 4–5 km for traveling pods, with the closest point of approach (CPA) being 3–4 km at an estimated received SPL of 157–164 dB re 1 μPa_{rms} (McCauley et al. 1998, 2000a). A greater stand-off range of 7–12 km was observed for more sensitive resting pods (cow-calf pairs; McCauley et al. 1998, 2000a). The mean received SPL for initial avoidance of an approaching airgun was 140 dB re 1 μPa_{rms} for humpback pods containing females, and at the mean CPA distance the received SPL was 143 dB re 1 μPa_{rms}. One startle response was reported for a SPL of 112 dB re 1 μPa_{rms}. The initial avoidance response generally occurred at distances of 5–8 km from the airgun array and 2 km from the single airgun. However, some individual humpback whales, especially males, approached within distances of 100–400 m, where the maximum received SPL was 179 dB re 1 μPa_{rms}. The McCauley et al. (1998, 2000a,b) studies show

evidence of greater avoidance of seismic airgun sounds by pods with females than by other pods during humpback migration off Western Australia. Studies examining the behavioral response of humpback whales off Eastern Australia to airguns are currently underway (Cato et al. 2011, 2012, 2013).

Humpback whales on their summer feeding grounds in southeast Alaska did not exhibit persistent avoidance when exposed to seismic pulses from a 1.64-L (100 in^3) airgun (Malme et al. 1985). Some humpbacks seemed "startled" at received SPLs of 150–169 dB re 1 μPa. Malme et al. (1985) concluded that there was no clear evidence of avoidance, despite the possibility of subtle effects, at received SPLs up to 172 re 1 μPa on an approximate rms basis. However, Moulton and Holst (2010) reported that humpback whales monitored during seismic surveys in the Northwest Atlantic had significantly lower sighting rates and were most often seen swimming away from the vessel during seismic periods compared with periods when airguns were silent.

Among wintering humpback whales off Angola (n = 52 useable groups), there were no significant differences in encounter rates (sightings/hr) when a 24-airgun array (3147 in^3 or 5085 in^3) was operating vs. silent (Weir 2008a). There was also no significant difference in the mean CPA (closest observed point of approach) distance of the humpback sightings when airguns were on vs. off (3050 m vs. 2700 m, respectively). Cerchio et al. (2014) suggested that the breeding display of humpback whales off Angola may be disrupted by seismic sounds, as singing activity declined with increasing received levels.

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). The evidence for this was circumstantial and subject to alternative explanations (IAGC 2004). Also, the evidence was not consistent with subsequent results from the same area of Brazil (Parente et al. 2006), or with direct studies of humpbacks exposed to seismic surveys in other areas and seasons (see above). After allowance for data from subsequent years, there was "no observable direct correlation" between strandings and seismic surveys (IWC 2007, p. 236).

Bowhead Whale

Responsiveness of bowhead whales to seismic surveys can be quite variable depending on their activity (feeding vs. migrating). Bowhead whales on their summer feeding grounds in the Canadian Beaufort Sea showed no obvious reactions to pulses from seismic vessels at distances of 6–99 km and received sound levels of 107–158 dB on an approximate rms basis (Richardson et al. 1986); their general activities were indistinguishable from those of a control group. However, bowheads usually did show strong avoidance responses when seismic vessels approached within a few kilometres (~3–7 km) and when received levels of airgun sounds were 152–178 dB (Richardson et al. 1986, 1995; Ljungblad et al. 1988; Miller et al. 2005). They also moved away when a single airgun was activated nearby (Richardson et al. 1986; Ljungblad et al. 1988). In one case, bowheads engaged in near-bottom feeding began to turn away from a 30-airgun array with a source level of 248 dB re 1 μPa · m at a distance of 7.5 km, and swam away when it came within ~2 km; some whales continued feeding until the vessel was 3 km away (Richardson et al. 1986). This work and subsequent summer studies in the same region showed that many feeding bowhead whales tend to tolerate higher sound levels than migrating bowhead whales (see below) before showing an overt change in behavior (e.g., Miller et al. 2005; Harris et al. 2007; Robertson et al. 2013). On the summer feeding grounds, bowhead whales are often seen from an operating seismic ship, though average sighting distances tend to be larger when the airguns are operating. Similarly, preliminary analyses of data from the Alaskan Beaufort Sea indicate that bowheads feeding there during late summer and autumn also did not display large-scale distributional changes in relation to seismic operations

(Christie et al. 2009; Koski et al. 2009). However, some individual bowheads apparently begin to react at distances a few kilometres away, beyond the distance at which observers on the ship can sight bowheads (Richardson et al. 1986; Citta et al. 2007). The feeding whales may be affected by the sounds, but the need to feed may reduce the tendency to move away until the airguns are within a few kilometres.

Migrating bowhead whales in the Alaskan Beaufort Sea seem more responsive to sound pulses from a distant seismic vessel compared to summering bowheads. Bowhead whales migrating west across the Alaskan Beaufort Sea in autumn are unusually responsive, with substantial avoidance occurring out to distances of 20–30 km at received SPLs of around 120–130 dB re 1 μPa_{rms} from a medium-sized airgun source (Miller et al. 1999; Richardson et al. 1999; see also Manly et al. 2007). Those results came from 1996–98, when a partially-controlled study of the effect of Ocean Bottom Cable (OBC) seismic surveys on westward-migrating bowheads was conducted in late summer and autumn in the Alaskan Beaufort Sea. At times when the airguns were not active, many bowheads moved into the area close to the inactive seismic vessel. Avoidance of the area of seismic operations did not persist beyond 12–24 h after seismic surveying stopped. Preliminary analysis of recent data on traveling bowheads in the Alaskan Beaufort Sea also showed a stronger tendency to avoid operating airguns than was evident for feeding bowheads (Christie et al. 2009; Koski et al. 2009). Additionally, 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).

Bowhead whale calls detected in the presence and absence of airgun sounds have been studied extensively in the Beaufort Sea. Early work on the summering grounds in the Canadian Beaufort Sea showed that bowheads continue to produce calls of the usual types when exposed to airgun sounds, although numbers of calls detected may be somewhat lower in the presence of airgun pulses (Richardson et al. 1986). Studies during autumn in the Alaskan Beaufort Sea, one in 1996–1998 and another in 2007–2010, have shown that numbers of calls detected are significantly lower in the presence than in the absence of airgun pulses (Greene et al. 1999a,b; Blackwell et al. 2013; Koski et al. 2009; see also Nations et al. 2009). 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, and Blackwell et al. (2012) suggested that the cumulative SEL threshold for when bowhead whales cease calling is near 124 dB re 1 $\mu Pa^2 \cdot s$. This decrease could have resulted from movement of the whales away from the area of the seismic survey or a reduction in calling behavior, or a combination of the two. Aerial surveys showed that there was strong avoidance of the operating airguns during the 1996–98 study, when most of the whales appeared to be migrating (Miller et al. 1999; Richardson et al. 1999). In contrast, aerial surveys during 2007–2010 showed less consistent avoidance by the bowheads, many of which appeared to be feeding (Christie et al. 2009; Koski et al. 2009, 2011). The reduction in call detection rates during periods of airgun operation may have been more dependent on actual avoidance during the 1996–98 study and more dependent on reduced calling behavior during 2007–2010, but further analysis of the recent data is ongoing.

A recent 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 kilometres 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 are no data on reactions of bowhead whales to seismic surveys in winter or spring.

Gray Whale

Malme et al. (1986, 1988) studied the responses of feeding eastern gray whales to pulses from a single 100-in^3 airgun off St. Lawrence Island in the northern Bering Sea. They estimated, based on small sample sizes, that 50% of feeding gray whales stopped feeding at an average received sound pressure level of 173 dB re 1 μPa on an (approximate) rms basis, and that 10% of feeding whales interrupted feeding at received levels of 163 dB re 1 μPa_{rms}. Malme at al. (1986) estimated that an average pressure level of 173 dB occurred at a range of 2.6–2.8 km from an airgun array with a source level of 250 dB re 1 μPa_{peak} in the northern Bering Sea. These findings were generally consistent with the results of studies conducted on larger numbers of gray whales migrating off California (Malme et al. 1984; Malme and Miles 1985) and western Pacific gray whales feeding off Sakhalin, Russia (Würsig et al. 1999; Gailey et al. 2007; Johnson et al. 2007; Yazvenko et al. 2007a,b), along with a few data on gray whales off British Columbia (Bain and Williams 2006).

Malme and Miles (1985) concluded that, during migration off California, gray whales showed changes in swimming pattern with received levels of ~160 dB re 1 μPa and higher, on an approximate rms basis. The 50% probability of avoidance was estimated to occur at a CPA distance of 2.5 km from a 4000-in^3 airgun array operating off central California. This would occur at an average received SPL of ~170 dB re 1 μPa_{rms}. Some slight behavioral changes were noted when approaching gray whales reached the distances where received sound pressure levels were 140 to 160 dB re 1 μPa_{rms}, but these whales generally continued to approach (at a slight angle) until they passed the sound source at distances where received levels averaged ~170 dB re 1 μPa_{rms} (Malme et al. 1984; Malme and Miles 1985).

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). Also, there was evidence of 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). The 2001 seismic program, as well as a subsequent survey in 2010, involved an unusually comprehensive combination of real-time monitoring and mitigation measures designed to avoid exposing western gray whales to received SPLs of sound above about 163 dB re 1 μPa_{rms} (Johnson et al. 2007; Nowacek et al. 2012, 2013). The lack of strong avoidance or other strong responses was presumably in part a result of the mitigation measures. Effects probably would have been more significant without such intensive mitigation efforts. Limited data obtained during a monitoring program in 2010 indicated that an increase in vessel traffic and seismic operations may have displaced gray whales from their preferred feeding area (WWF et al. 2010). However, this study also reports that the number of gray whales in the area increased several days after seismic acquisition ceased.

Gray whales in British Columbia 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).

Rorquals

Blue, sei, fin, and minke whales (all of which are members of the genus *Balaenoptera*) often have been seen in areas where airgun sources are active (Stone 2003; MacLean and Haley 2004; Stone and Tasker 2006), and calls from blue and fin whales have been localized in areas with airgun operations (e.g., McDonald et al. 1995; Dunn and Hernandez 2009; Castellote et al. 2012). Sightings by observers on seismic vessels during 110 large-source seismic surveys off the U.K. from 1997 to 2000 suggest that, during times of good visibility, sighting rates for mysticetes (mainly fin and sei whales) were similar when large arrays of airguns were active vs. silent (Stone 2003; Stone and Tasker 2006). However, these whales tended to exhibit localized avoidance, remaining significantly further (on average) from the airgun array during seismic operations compared with non-seismic periods (P = 0.0057; Stone and Tasker 2006). The average CPA distances for baleen whales sighted when large airgun arrays were operating vs. silent were about 1.6 vs. 1.0 km. Baleen whales, as a group, were more often oriented away from the vessel while a large airgun array was active compared with periods of inactivity (P <0.05; Stone and Tasker 2006). Similarly, Castellote et al. (2012) reported that singing fin whales in the Mediterranean moved away from an operating airgun array and avoided the area for days after airgun activity had ceased. In addition, Stone (2003) noted that fin/sei whales were less likely to remain submerged during periods of seismic surveying.

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, the mean CPA distance for fin whales was significantly farther 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, MacLean and Haley (2004) reported that minke whales occasionally approached active airgun arrays where received sound levels were estimated to be near 170–180 dB re 1 μPa.

Discussion and Conclusions

Baleen whales generally tend to avoid operating airguns, but avoidance radii are quite variable. Whales are often reported to show no overt reactions to airgun pulses at distances beyond a few kilometers, even though the sound levels from airgun pulses remain well above ambient noise levels out to much longer distances. However, studies done since the late 1990s of migrating humpback and migrating bowhead whales show reactions, including avoidance, that sometimes extend to greater distances than documented earlier. Avoidance distances often exceed the distances at which boat-based observers can see whales, so observations from the source vessel can be biased. Observations over broader areas may be needed to determine the range of potential effects of some large-source seismic surveys where effects on cetaceans may extend to considerable distances (Richardson et al. 1999; Bain and Williams 2006; Moore and Angliss 2006). Longer-range observations, when required, can sometimes

be obtained via systematic aerial surveys or aircraft-based observations of behavior (e.g., Richardson et al. 1986, 1999; Miller et al. 1999, 2005; Yazvenko et al. 2007a,b) or by use of observers on one or more support vessels operating in coordination with the seismic vessel (e.g., Smultea et al. 2004; Johnson et al. 2007). However, the presence of other vessels near the source vessel can, at least at times, reduce sightability of cetaceans from the source vessel (Beland et al. 2009), thus complicating interpretation of sighting data.

Some baleen whales show considerable tolerance of seismic pulses. However, when the pulses are strong enough, avoidance or other behavioral changes become evident. Because responsiveness is variable and the responses become less obvious with diminishing received sound level, it has been difficult to determine the maximum distance (or minimum received sound level) at which reactions to seismic become evident and, hence, how many whales are affected. Responsiveness depends on the situation (Richardson et al. 1995; Ellison et al. 2012).

Studies of gray, bowhead, and humpback whales have determined that received levels of pulses in the 160–170 dB re 1 μPa_{rms} range seem to cause obvious avoidance behavior in a substantial fraction of the animals exposed. In many areas, sound from seismic airgun pulses diminish to these levels at distances ranging from 4 to 15 km from the source. A substantial proportion of the baleen whales within such distances may show avoidance or other strong disturbance reactions to the operating airgun array. However, in other situations, various mysticetes tolerate exposure to full-scale airgun arrays operating at even closer distances, with only localized avoidance and minor changes in activities. At the other extreme, in migrating bowhead whales, avoidance often extends to considerably larger distances (20–30 km) and lower received SPLs (120–130 dB re 1 μPa_{rms}). Also, even in cases where there is no conspicuous avoidance or change in activity upon exposure to sound pulses from distant seismic operations, there are sometimes subtle changes in behavior (e.g., surfacing–respiration–dive cycles) that are only evident through detailed statistical analysis (e.g., Richardson et al. 1986; Gailey et al. 2007).

Mitigation measures for seismic surveys, especially nighttime seismic surveys, typically assume that many marine mammals (at least baleen whales) tend to avoid approaching airguns, or the seismic vessel itself, before being exposed to levels high enough for there to be any possibility of injury. This assumes that the ramp-up (soft-start) procedure is used when commencing airgun operations, to give whales near the vessel the opportunity to move away before they are exposed to sound levels that might be strong enough to elicit TTS. As noted above, single-airgun experiments with three species of baleen whales show that those species typically do tend to move away when a single airgun is activated nearby, which simulates the onset of a ramp up. The three species that showed avoidance when exposed to the onset of pulses from a single airgun were *gray whales* (Malme et al. 1984, 1986, 1988); *bowhead whales* (Richardson et al. 1986; Ljungblad et al. 1988); and *humpback whales* (Malme et al. 1985; McCauley et al. 1998, 2000a,b). In addition, results from Moulton and Holst (2010) showed that, during operations with a single airgun and during ramp up, blue whales were seen significantly farther from the vessel compared with periods without airgun operations. Since startup of a single airgun is equivalent to the start of a ramp up (=soft start), this strongly suggests that many baleen whales will begin to move away during the initial stages of a ramp-up.

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. Castellote et al. (2012) reported that fin whales avoided their potential winter ground for an extended period of time (at least 10 days) after seismic operations in the Mediterranean Sea had ceased. However, gray whales have continued to

migrate annually along the west coast of North America despite intermittent seismic exploration (and much ship traffic) in that area for decades (Appendix A *in* Malme et al. 1984; Richardson et al. 1995), and there has been a substantial increase in the population over recent decades (Allen and Angliss 2013). The western Pacific gray whale population did not seem affected by a seismic survey in its feeding ground during a prior year (Johnson et al. 2007). Similarly, bowhead whales have continued to travel to the eastern Beaufort Sea each summer despite seismic exploration in their summer and autumn range for many years (Richardson et al. 1987), and their numbers have increased notably (Allen and Angliss 2013). Bowheads also have been observed over periods of days or weeks in areas ensonified repeatedly by sound from seismic airgun pulses (Richardson et al. 1987; Harris et al. 2007). However, it is generally not known whether the same individual bowheads were involved in these repeated observations (within and between years) in strongly ensonified areas. In any event, in the absence of some unusual circumstances, the history of coexistence between seismic surveys and baleen whales suggests that brief exposures to sound pulses from any single seismic survey are unlikely to result in prolonged disturbance effects.

1.5.2 Toothed Whales

Historically, little systematic information is available about reactions of toothed whales to sound pulses. Few studies similar to the more extensive baleen whale/seismic pulse work summarized above have been reported for toothed whales. However, there are recent systematic data on sperm whales (e.g., Gordon et al. 2006; Madsen et al. 2006; Winsor and Mate 2006; Jochens et al. 2008; Miller et al. 2009). There is also an increasing amount of information about responses of various odontocetes to seismic surveys based on monitoring studies (e.g., Stone 2003; Smultea et al. 2004; Moulton and Miller 2005; Bain and Williams 2006; Holst et al. 2006; Stone and Tasker 2006; Potter et al. 2007; Hauser et al. 2008; Holst and Smultea 2008; Weir 2008a; Barkaszi et al. 2009; Richardson et al. 2009; Moulton and Holst 2010; Wole and Myade 2014).

Delphinids (Dolphins and similar) and Monodontids (Beluga and Narwhal)

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., Goold 1996a,b,c; Calambokidis and Osmek 1998; Stone 2003; Moulton and Miller 2005; Holst et al. 2006; Stone and Tasker 2006; Weir 2008a; Barkaszi et al. 2009; Richardson et al. 2009; Moulton and Holst 2010; Wole and Myade 2014). 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. Studies that have reported cases of small toothed whales close to the operating airguns include Duncan (1985), Arnold (1996), Stone (2003), and Holst et al. (2006). When a 3959 in^3, 18-airgun array was firing off California, toothed whales behaved in a manner similar to that observed when the airguns were silent (Arnold 1996). Some dolphins seem to be attracted to the seismic vessel and floats, and some ride the bow wave of the seismic vessel even when a large array of airguns is firing (e.g., Moulton and Miller 2005). Nonetheless, small toothed whales more often tend to head away, or to maintain a somewhat greater distance from the vessel, when a large array of airguns is operating than when it is silent (e.g., Stone and Tasker 2006; Weir 2008a; Moulton and Holst 2010; Barry et al. 2012).

Weir (2008b) noted that a group of short-finned pilot whales initially showed an avoidance response to ramp up of a large airgun array, but that this response was limited in time and space. Moulton and Holst (2010) did not find any indications that long-finned pilot whales, or delphinids as a group, responded to ramp ups by moving away from the seismic vessel during surveys in the Northwest Atlantic.

Although the ramp-up procedure is a widely-used mitigation measure, it remains uncertain how effective it is at alerting marine mammals (especially odontocetes) and causing them to move away from seismic operations (Weir 2008b; Cato et al. 2013; Weilgart 2014). Exposure modeling may be useful to evaluate and optimize ramp-up procedures for intense sound sources (von Benda-Beckmann et al. 2013).

Goold (1996a,b,c) studied the effects on common dolphins of 2D seismic surveys in the Irish Sea. Passive acoustic surveys were conducted from the "guard ship" that towed a hydrophone. The results indicated that there was a local displacement of dolphins around the seismic operation. However, observations indicated that the animals were tolerant of the sounds at distances outside a 1-km radius from the airguns (Goold 1996a). Initial reports of larger-scale displacement were later shown to represent a normal autumn migration of dolphins through the area, and were not attributable to seismic surveys (Goold 1996a,b,c).

The beluga whale is a species that (at least at times) shows long-distance avoidance of seismic vessels. Aerial surveys conducted in the southeastern Beaufort Sea in summer found that sighting rates of belugas were significantly lower at distances 10–20 km compared with 20–30 km from an operating airgun array (Miller et al. 2005). The low number of beluga sightings by marine mammal observers on the vessel seemed to confirm there was a strong avoidance response to the 2250 in^3 airgun array. More recent seismic monitoring studies in the same area have confirmed that the apparent displacement effect on belugas extended farther than has been shown for other small odontocetes exposed to airgun pulses (e.g., Harris et al. 2007). 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.

Observers stationed on seismic vessels operating off the U.K. from 1997 to 2000 have provided data on the occurrence and behavior of various toothed whales exposed to seismic pulses (Stone 2003; Gordon et al. 2004; Stone and Tasker 2006). Dolphins of various species often showed more evidence of avoidance of operating airgun arrays than has been reported previously for small odontocetes. Sighting rates of white-sided dolphins, white-beaked dolphins, *Lagenorhynchus* spp., and all small odontocetes combined were significantly lower during periods when large-volume[5] airgun arrays were active. Except for the pilot whale and bottlenose dolphin, CPA distances for all of the small odontocete species tested, including killer whales, were significantly farther from large airgun arrays during periods of airgun activity compared with periods of inactivity. Pilot whales were less responsive than other small odontocetes in the presence of seismic surveys (Stone and Tasker 2006). For small odontocetes as a group, and most individual species, orientations differed between times when large airgun arrays were operating vs. silent, with significantly fewer animals traveling towards and/or more traveling away from the vessel during airgun activation (Stone and Tasker 2006). Observers' records suggested that fewer cetaceans were feeding and fewer were interacting with the survey vessel (e.g., bow-riding) during periods with airguns operating, and small odontocetes tended to swim faster during periods of airgun activation (Stone and Tasker 2006). For most types of small odontocetes sighted by observers on seismic vessels, the median CPA distance was ≥0.5 km larger during airgun operations (Stone and Tasker 2006). Killer whales appeared to be more tolerant of seismic surveying in deeper waters.

[5] Large volume means at least 1300 in^3, with most (79%) at least 3000 in^3.

Data collected during seismic operations in the Gulf of Mexico and off Central America show similar patterns. A summary of vessel-based monitoring data from the Gulf of Mexico during 2003–2008 showed that delphinids were generally seen farther from the vessel during seismic than during non-seismic periods (based on Barkaszi et al. 2009, excluding sperm whales). Similarly, during two NSF-funded L-DEO seismic surveys that used a large 20 airgun array (~7000 in^3), sighting rates of delphinids were lower and initial sighting distances were farther away from the vessel during periods when the seismic source was active versus not active (Smultea et al. 2004; Holst et al. 2005a, 2006; Holst 2009; Richardson et al. 2009). Monitoring results during a seismic survey in the Southeast Caribbean showed that the mean CPA of delphinids was 991 m during seismic operations vs. 172 m when the airguns were not operational (Smultea et al. 2004). Surprisingly, nearly all acoustic detections via a towed passive acoustic monitoring (PAM) array, including both delphinids and sperm whales, were made when the airguns were operating (Smultea et al. 2004). Although the number of sightings during monitoring of a seismic survey off the Yucatán Peninsula, Mexico, was small (n = 19), the results showed that the mean CPA distance of delphinids there was 472 m during seismic operations vs. 178 m when the airguns were silent (Holst et al. 2005a). The acoustic detection rates were nearly 5 times higher without than with seismic operations (Holst et al. 2005a). During a seismic survey off Taiwan for which the sample size was small (n = 14), Holst (2009) noted that the mean CPA distance of delphinids during seismic operations (1698 m) was greater compared with non-seismic periods (888 m).

For two additional NSF-funded L-DEO seismic surveys in the Eastern Tropical Pacific, both using a large 36-airgun array (~6600 in^3), the results are less easily interpreted (Richardson et al. 2009). During both surveys, the delphinid detection rate was lower during periods when the seismic source was active versus not active, as found in various other projects, but the mean CPA distance of delphinids was closer (not farther) during seismic periods (Hauser et al. 2008; Holst and Smultea 2008).

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 *ca.* 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.

Among Atlantic spotted dolphins off Angola (n = 16 useable groups), marked short-term and localized displacement was found in response to seismic operations conducted with a 24-airgun array (3147 in^3 or 5085 in^3) (Weir 2008a). Sample sizes were low, but CPA distances of dolphin groups were significantly larger when airguns were on (mean 1080 m) vs. off (mean 209 m). No Atlantic spotted dolphins were seen within 500 m of the airguns when they were operating, whereas all sightings when airguns were silent occurred within 500 m, including the only recorded "positive approach" behaviors.

Reactions of toothed whales to a single airgun or other small airgun source are not well documented, but tend to be less substantial than reactions to large airgun arrays (e.g., Stone 2003; Stone and Tasker 2006). During 91 site surveys off the U.K. in 1997–2000, sighting rates of all small odontocetes combined were significantly lower during periods the low-volume[6] airgun sources were operating, and effects on orientation were evident for all species and groups tested (Stone and Tasker 2006). Results from four NSF-funded L-DEO seismic surveys using small arrays (up to 3 GI guns and 315 in^3) were inconclusive. During surveys in the Eastern Tropical Pacific (Holst et al. 2005b) and in the Northwest Atlantic (Haley and Koski 2004), detection rates were slightly lower during periods when the seismic

[6] For low volume arrays, maximum volume was 820 in^3, with most (87%) ≤180 in^3.

source was active versus not active. However, mean CPAs were closer during seismic operations during one cruise (Holst et al. 2005b), and greater during another cruise (Haley and Koski 2004). Interpretation of the data was confounded by the fact that survey effort and/or number of sightings during periods when the source was not active during both surveys was small. Results from another two small-array surveys were even more variable (MacLean and Koski 2005; Smultea and Holst 2008; Holst and Robertson 2009).

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 (Finneran et al. 2000, 2002, 2005). Finneran et al. (2002) exposed a captive bottlenose dolphin and beluga to single impulses from a water gun (80 in^3). As compared with airgun pulses, water gun impulses were expected to contain proportionally more energy at higher frequencies because there is no significant gas-filled bubble, and thus little low-frequency bubble-pulse energy (Hutchinson and Detrick 1984). The captive animals sometimes vocalized after exposure and exhibited reluctance to station at the test site where subsequent exposure to impulses would be implemented (Finneran et al. 2002). Similar behaviors were exhibited by captive bottlenose dolphins and a beluga exposed to single underwater pulses designed to simulate those produced by distant underwater explosions (Finneran et al. 2000). It is uncertain what relevance these observed behaviors in captive, trained marine mammals exposed to single transient sounds may have to free-ranging animals exposed to multiple pulses. In any event, the animals tolerated rather high received levels of sound before exhibiting the aversive behaviors mentioned above.

Odontocete responses (or lack of responses) to sound pulses from underwater explosions (as opposed to airgun pulses) may be indicative of odontocete responses to very strong sound pulses. During the 1950s, small explosive charges were dropped into an Alaskan river in attempts to scare beluga whales away from salmon. Success was limited (Fish and Vania 1971; Frost et al. 1984). Small explosive charges were "not always effective" in moving bottlenose dolphins away from sites in the Gulf of Mexico where larger demolition blasts were about to occur (Klima et al. 1988). Odontocetes may be attracted to fish killed by explosions, and thus attracted rather than repelled by "scare" charges. Captive false killer whales showed no obvious reaction to single sound pulses from small (10 g) charges; the received level was ~185 dB re 1 μPa (Akamatsu et al. 1993). Jefferson and Curry (1994) reviewed several additional studies that found limited or no effects of sound pulses from small explosive charges on killer whales and other odontocetes. Aside from the potential for causing auditory impairment (see below), the tolerance to these charges may indicate a lack of effect, or the failure to move away may simply indicate a stronger desire to feed, regardless of circumstances.

Phocoenids (Porpoises)

Porpoises, like delphinids, show variable reactions to seismic operations, and reactions apparently depend on species. The limited available data suggest that harbor porpoises show stronger avoidance of seismic operations than do Dall's porpoises (Stone 2003; MacLean and Koski 2005; Bain and Williams 2006). In Washington State waters, the harbor porpoise—despite being considered a high-frequency specialist—appeared to be the species affected by the lowest received SPL of airgun sound (<145 dB re 1 μPa_{rms} at a distance >70 km; Bain and Williams 2006). Similarly, during seismic surveys with large airgun arrays off the U.K. in 1997–2000, there were significant differences in directions of travel by harbor porpoises during periods when the airguns were active vs. silent (Stone 2003; Stone and Tasker 2006). A captive harbor porpoise exposed to single sound pulses from a small airgun showed aversive behavior upon receipt of a pulse with received SPL above 174 dB re 1 $\mu Pa_{pk\text{-}pk}$ or SEL >145 dB re 1 $\mu Pa^2 \cdot s$ (Lucke et al. 2009). 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) noted that the probability of recording a porpoise buzz decreased by 15% within the ensonified area, and that the probability was positively related to the distance from the seismic ship; this is turn, may show decreased foraging efficiency. Nonetheless, animals returned to the area within a few hours (Thompson et al. 2013). Kastelein et al. (2013c) noted that a harbor porpoise showed no response to an impulse sound below an SEL of 65 dB , but a 50% brief response rate was noted at a SEL of 92 dB and an SPL of 122 dB re 1 $\mu Pa_{0\text{-peak}}$.

In contrast to harbor porpoise, Dall's porpoises seem relatively tolerant of airgun operations (MacLean and Koski 2005; Bain and Williams 2006), although they too have been observed to avoid large arrays of operating airguns (Calambokidis and Osmek 1998; Bain and Williams 2006). The apparent tendency for greater responsiveness in the harbor porpoise is consistent with their relative responsiveness to boat traffic and some other acoustic sources (Richardson et al. 1995; Southall et al. 2007).

Beaked Whales

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 behavior in response to sound from vessels (e.g., Pirotta et al. 2012). They may also dive for an extended period when approached by a vessel (e.g., Kasuya 1986), although it is uncertain how much longer such dives may be as compared to dives by undisturbed beaked whales, which also are often quite long (Baird et al. 2006; Tyack et al. 2006b). In any event, it is likely that most beaked whales would also show strong avoidance of an approaching seismic vessel, regardless of whether or not the airguns are operating. However, this has not been documented explicitly. Also, northern bottlenose whales sometimes are quite tolerant of slow-moving vessels not emitting airgun pulses (Reeves et al. 1993; Hooker et al. 2001). Detections (acoustic or visual) of northern bottlenose whales have been made from seismic vessels during recent seismic surveys in the Northwest Atlantic during periods with and without airgun operations (Potter et al. 2007; Moulton and Miller 2005). Similarly, other visual and acoustic studies indicated that 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 (Gosselin and Lawson 2004; Laurinolli and Cochrane 2005; Simard et al. 2005).

There are increasing indications that some beaked whales tend to strand when military exercises involving mid-frequency sonar operation are ongoing nearby (e.g., Simmonds and Lopez-Jurado 1991; Frantzis 1998; NOAA and USN 2001; Jepson et al. 2003; Barlow and Gisiner 2006; D'Amico et al. 2009; Filadelfo et al. 2009; see also the "Strandings and Mortality" subsection, later). These strandings are apparently at least in part a disturbance response, although auditory or other injuries or other physiological effects may also be a factor. Whether beaked whales would ever react similarly to seismic surveys is unknown. Seismic survey sounds are quite different from those of the sonars in operation during the above-cited incidents. No conclusive link has been established between seismic surveys and beaked whale strandings. There was a stranding of two Cuvier's beaked whales in the Gulf of California (Mexico) in September 2002 when the R/V *Maurice Ewing* was conducting a seismic survey in the general area (e.g., Malakoff 2002; Hildebrand 2005). However, NMFS did not establish a cause and effect relationship between this stranding and the seismic survey activities (Hogarth 2002). Cox et al. (2006) noted the "lack of knowledge regarding the temporal and spatial correlation between the [stranding] and the sound source". Hildebrand (2005) illustrated the approximate temporal-spatial relationships between the stranding and the *Ewing*'s tracks, but the time of the stranding was not known with sufficient

precision for accurate determination of the CPA distance of the whales to the *Ewing*. Another stranding of Cuvier's beaked whales in the Galápagos occurred during a seismic survey in April 2000; however "There is no obvious mechanism that bridges the distance between this source and the stranding site" (Gentry [ed.] 2002).

Sperm Whales

All three species of sperm whales have been reported to show avoidance reactions to standard vessels not emitting airgun sounds (e.g., Richardson et al. 1995; Würsig et al. 1998; McAlpine 2002; Baird 2005). However, most studies of the sperm whale *Physeter macrocephalus* exposed to airgun sounds indicate that this species shows considerable tolerance of airgun pulses. The whales usually do not show strong avoidance (i.e., they do not leave the area) and they continue to call.

There were some early and limited observations suggesting that sperm whales in the Southern Ocean ceased calling during some (but not all) times when exposed to weak airgun pulses from extremely distant (>300 km) seismic exploration. However, other operations in the area could also have been a factor (Bowles et al. 1994). This "quieting" was suspected to represent a disturbance effect, in part because sperm whales exposed to pulsed man-made sounds at higher frequencies often cease calling (Watkins and Schevill 1975; Watkins et al. 1985). Also, there was an early preliminary account of possible long-range avoidance of seismic vessels by sperm whales in the Gulf of Mexico (Mate et al. 1994). However, this has not been substantiated by subsequent more detailed work in that area (Gordon et al. 2006; Winsor and Mate 2006; Jochens et al. 2008; Miller et al. 2009).

Recent and more extensive data from vessel-based monitoring programs in U.K. waters and off eastern Canada and Angola suggest that sperm whales in those areas show little evidence of avoidance or behavioral disruption in the presence of operating seismic vessels (Stone 2003; Stone and Tasker 2006; Weir 2008a; Moulton and Holst 2010). Among sperm whales off Angola (n = 96 useable groups), there were no significant differences in encounter rates (sightings/hr) when a 24-airgun array (3147 in^3 or 5085 in^3) was operating vs. silent (Weir 2008a). There was also no significant difference in the CPA distances of the sperm whale sightings when airguns were on vs. off (means 3039 m vs. 2594 m, respectively). Encounter rate tended to increase over the 10-month duration of the seismic survey. Similarly, in the Northwest Atlantic, sighting rates and distances of sperm whales did not differ between periods when airguns were on vs. off (Moulton and Holst 2010). These types of observations are difficult to interpret because the observers are stationed on or near the seismic vessel, and may underestimate reactions by some of the more responsive animals, which may be beyond visual range. However, these results do seem to show considerable tolerance of seismic surveys by at least some sperm whales. Also, a study off northern Norway indicated that sperm whales continued to call when exposed to pulses from a distant seismic vessel. Received SPLs of the seismic pulses were up to 146 dB re 1 $\mu Pa_{p\text{-}p}$ (Madsen et al. 2002).

Similarly, a study conducted off Nova Scotia that analyzed recordings of sperm whale vocalizations at various distances from an active seismic program did not detect any obvious changes in the distribution or behavior of sperm whales (McCall Howard 1999).

Sightings of sperm whales by observers on seismic vessels operating in the Gulf of Mexico during 2003–2008 were at very similar average distances regardless of the airgun operating conditions (Barkaszi et al. 2009). For example, the mean sighting distance was 1839 m when the airgun array was in full operation (n=612) vs. 1960 m when all airguns were off (n=66).

A controlled study of the reactions of tagged sperm whales to seismic surveys was done in the Gulf of Mexico — the Sperm Whale Seismic Study or SWSS (Gordon et al. 2006; Madsen et al. 2006; Winsor

and Mate 2006; Jochens et al. 2008; Miller et al. 2009). During SWSS, D-tags (Johnson and Tyack 2003) were used to record the movement and acoustic exposure of eight foraging sperm whales before, during, and after controlled exposures to sound from airgun arrays (Jochens et al. 2008; Miller et al. 2009). Whales were exposed to maximum received SPLs of 111–147 dB re 1 μPa_{rms} (131–162 dB re 1 $\mu Pa_{pk\text{-}pk}$) at ranges of ~1.4–12.8 km from the sound source (Miller et al. 2009). Although the tagged whales showed no discernible horizontal avoidance, some whales showed changes in diving and foraging behavior during full-array exposure, possibly indicative of subtle negative effects on foraging (Jochens et al. 2008; Miller et al. 2009; Tyack 2009). Two indications of foraging that they studied were oscillations in pitch and occurrence of echolocation buzzes, both of which tend to occur when a sperm whale closes-in on prey. "Oscillations in pitch generated by swimming movements during foraging dives were on average 6% lower during exposure than during the immediately following post-exposure period, with all 7 foraging whales exhibiting less pitching (P = 0.014). Buzz rates, a proxy for attempts to capture prey, were 19% lower during exposure…" (Miller et al. 2009). Although the latter difference was not statistically significant (P = 0.141), the percentage difference in buzz rate during exposure vs. post-exposure conditions appeared to be strongly correlated with airgun-whale distance (Miller et al. 2009: Fig. 5; Tyack 2009).

Discussion and Conclusions

Dolphins and porpoises are often seen by observers on active seismic vessels, occasionally at close distances (e.g., bow riding). However, some studies near the U.K., Newfoundland and Angola, in the Gulf of Mexico, and off Central America have shown localized avoidance. Also, beluga whales summering in the Canadian Beaufort Sea showed larger-scale avoidance, tending to avoid waters out to 10–20 km from operating seismic vessels. In contrast, recent studies show little evidence of conspicuous reactions by sperm whales to airgun pulses, contrary to earlier indications.

There are almost no specific data on responses of beaked whales to seismic surveys, but it is likely that most if not all species show strong avoidance. There is increasing evidence that some beaked whales may strand after exposure to strong sound from sonars. Whether they ever do so in response to seismic survey sound is unknown. Northern bottlenose whales seem to continue to call when exposed to pulses from distant seismic vessels.

Overall, odontocete reactions to large arrays of airguns are variable and, at least for delphinids and some porpoises, seem to be confined to a smaller radius than has been observed for some mysticetes. However, other data suggest that some odontocetes species, including beluga whales and harbor porpoises, may be more responsive than might be expected given their poor low-frequency hearing. Reactions at longer distances may be particularly likely when sound propagation conditions are conducive to transmission of the higher-frequency components of airgun sound to the animals' location (DeRuiter et al. 2006; Goold and Coates 2006; Tyack et al. 2006a; Potter et al. 2007).

For delphinids, and possibly the Dall's porpoise, the available data suggest that a ≥170 dB re 1 μPa_{rms} disturbance criterion (rather than ≥160 dB) would be appropriate. With a medium-to-large airgun array, received SPLs typically diminish to 170 dB within 1–4 km, whereas levels typically remain above 160 dB out to 4–15 km (e.g., Tolstoy et al. 2009). Reaction distances for delphinids are more consistent with the typical 170 dB re 1 μPa_{rms} distances. The 160 dB (rms) criterion currently applied by NMFS was developed based primarily on data from gray and bowhead whales. Avoidance distances for delphinids and Dall's porpoises tend to be shorter than for those two mysticete species. For delphinids and Dall's porpoises, there is no indication of strong avoidance or other disruption of behavior at distances beyond those where received levels would be ~170 dB re 1 μPa_{rms}.

1.5.3 Pinnipeds

Few studies of the reactions of pinnipeds to sound from open-water seismic exploration have been published (for review of the early literature, see Richardson et al. 1995). However, pinnipeds have been observed during a number of seismic monitoring studies. Monitoring in the Beaufort Sea during 1996–2002 provided a substantial amount of information on avoidance responses (or lack thereof) and associated behavior. Additional monitoring of that type has been done in the Beaufort and Chukchi Seas in 2006–2009. Pinnipeds exposed to seismic surveys have also been observed during seismic surveys along the U.S. west coast. Some limited data are available on physiological responses of pinnipeds exposed to seismic sound, as studied with the aid of radio telemetry. Also, there are data on the reactions of pinnipeds to various other related types of impulsive sounds.

Early observations provided considerable evidence that pinnipeds are often quite tolerant of strong pulsed sounds. During seismic exploration off Nova Scotia, gray seals exposed to sound from airguns and linear explosive charges reportedly did not react strongly (J. Parsons *in* Greene et al. 1985). An airgun caused an initial startle reaction among South African fur seals but was ineffective in scaring them away from fishing gear (Anonymous 1975). Pinnipeds in both water and air sometimes tolerate strong sound pulses from non-explosive and explosive scaring devices, especially if attracted to the area for feeding or reproduction (Mate and Harvey 1987; Reeves et al. 1996). Thus, pinnipeds are expected to be rather tolerant of, or to habituate to, repeated underwater sounds from distant seismic sources, at least when the animals are strongly attracted to the area.

In the U.K., a radio-telemetry study demonstrated short-term changes in the behavior of harbor (common) and gray seals exposed to airgun pulses (Thompson et al. 1998). Harbor seals were exposed to sound pulses from a 90-in^3 array (3 × 30 in^3 airguns), and behavioral responses differed among individuals. One harbor seal avoided the array at distances up to 2.5 km from the source and only resumed foraging dives after the source stopped. Another harbor seal exposed to the same small airgun array showed no detectable behavioral response, even when the array was within 500 m. Gray seals exposed to sound from a single 10-in^3 airgun showed an avoidance reaction: they moved away from the source, increased swim speed and/or dive duration, and switched from foraging dives to predominantly transit dives. These effects appeared to be short-term as gray seals either remained in, or returned at least once to, the foraging area where they had been exposed to sound pulses from airguns. These results suggest that there are interspecific as well as individual differences in seal responses to seismic sounds.

Off California, visual observations from a seismic vessel showed that California sea lions "typically ignored the vessel and array. When [they] displayed behavior modifications, they often appeared to be reacting visually to the sight of the towed array. At times, California sea lions were attracted to the array, even when it was on. At other times, these animals would appear to be actively avoiding the vessel and array" (Arnold 1996). In Puget Sound, sighting distances for harbor seals and California sea lions tended to be larger when airguns were operating; both species tended to orientate away whether or not the airguns were active (Calambokidis and Osmek 1998). Bain and Williams (2006) also stated that their small sample of harbor seals and sea lions tended to orientate and/or move away upon exposure to sounds from a large airgun array.

Monitoring work in the Alaskan Beaufort Sea during 1996–2001 provided considerable information regarding the behavior of seals exposed to sound pulses from seismic airguns (Harris et al. 2001; Moulton and Lawson 2002). Those seismic projects usually involved arrays of 6–16 airguns with total volumes of 560–1500 in^3. Subsequent monitoring work in the Canadian Beaufort Sea in 2001–2002, with a somewhat larger airgun system (24 airguns, 2250 in^3), provided similar results (Miller et al. 2005). The

combined results suggest that some seals avoid the immediate area around seismic vessels. In most survey years, ringed seal sightings averaged somewhat farther away from the seismic vessel when the air-guns were operating than when they were not (Moulton and Lawson 2002). Also, seal sighting rates at the water surface were lower during airgun array operations than during no-airgun periods in each survey year except 1997. However, the avoidance movements were relatively small, on the order of 100 m to (at most) a few hundreds of metres, and many seals remained within 100–200 m of the trackline as the operating airgun array passed by.

The operation of the airgun array had minor and variable effects on the behavior of seals visible at the surface within a few hundred metres of the airguns (Moulton and Lawson 2002). The behavioral data indicated that some seals were more likely to swim away from the source vessel during periods of airgun operations and more likely to swim towards or parallel to the vessel during periods when the source was not active. No consistent relationship was observed between exposure to airgun sound and proportions of seals engaged in other recognizable behaviors, e.g., "looked" and "dove". Such a relationship might have occurred if seals seek to reduce exposure to strong sound pulses, given the reduced airgun sound levels close to the surface where "looking" occurs (Moulton and Lawson 2002).

Monitoring results from the Canadian Beaufort Sea during 2001–2002 were more variable (Miller et al. 2005). During 2001, sighting rates of seals (mostly ringed seals) were similar independent of source activity, including periods without airgun operations. However, seals tended to be seen closer to the vessel during periods when no source was active vs. active. In contrast, during 2002, sighting rates of seals were higher during, and seals were seen farther from the vessel periods when no source was active vs. active (a marginally significant result). The combined data for both years showed that sighting rates were higher during periods when no source was active vs. active, and that sighting distances were similar independent of source activity. Miller et al. (2005) concluded that seals showed very limited avoidance to the operating airgun array.

Vessel-based monitoring also took place in the Alaskan Chukchi and Beaufort seas during 2006–2008 (Funk et al. 2010). These observations indicate a tendency for phocid seals to exhibit localized avoidance of the seismic source vessel when airguns are active (Funk et al. 2010). In the Chukchi Sea, seal sightings rates were greater when no source was active from source vessels at locations with received sound levels (RLs) ≥160 and 159–120 dB re 1 μPa_{rms}. Also, sighting rates were greater from source than monitoring vessels at locations with RLs <120 dB rms (Haley et al. 2010). In the Beaufort Sea, seal sighting rates in areas with RLs ≥160 dB rms were also significantly higher from monitoring than from seismic source vessels, and sighting rates were significantly higher from source vessels in areas exposed to <120 compared to ≥160 dB rms (Savarese et al. 2010). In addition, seals tended to stay farther away and swam away from source vessels more frequently than from monitoring vessels when RLs were ≥160 dB rms. Over the three years, seal sighting rates were greater from monitoring than source vessels at locations with received sound levels ≥160 and 159–120 dB rms, whereas seal sighting rates were greater from source than monitoring vessels at locations with RLs <120 dB rms, suggesting that seals may be reacting to active airguns by moving away from the source vessel.

Walruses near operating seismic surveys tend to swim away from the vessel (Hannay et al. 2011). Walrus calls were monitored during a low-energy shallow-hazards survey in 2009 and a 3-D seismic survey in 2010 (Hannay et al. 2010). During the shallow-hazard survey using a 40 in^3 airgun, walrus call detections stopped at SPLs >130 dB re 1 μPa_{rms} and declined at lower SPLs. During the large-array 3-D seismic survey, acoustic detections were negatively correlated with SPL at RLs of 110–140 dB, but no

detections were made at SPLs >140 dB dB re 1 μPa_{rms}. Hannay et al. (2011) suggested that walruses likely reduced calling rates upon exposure to higher SPLs without leaving the area.

In summary, visual monitoring from seismic vessels has shown only slight (if any) avoidance of airguns by pinnipeds, and only slight (if any) changes in behavior. These studies show that many pinnipeds do not avoid the area within a few hundred metres of an operating airgun array. However, based on the studies with large sample size, or observations from a separate monitoring vessel, or radio telemetry, it is apparent that some phocid seals do show localized avoidance of operating airguns. The limited nature of this tendency for avoidance is a concern. It suggests that one cannot rely on pinnipeds to move away, or to move very far away, before received levels of sound from an approaching seismic survey vessel approach those that may cause hearing impairment (see below).

1.6. Hearing Impairment and Other Physical Effects of Seismic Surveys

Temporary or permanent hearing impairment is a possibility when marine mammals are exposed to very strong sounds. Temporary threshold shift (TTS) has been demonstrated and studied in certain captive odontocetes and pinnipeds exposed to strong sounds (reviewed in Southall et al. 2007). However, there has been no specific documentation of TTS let alone permanent hearing damage, i.e. permanent threshold shift (PTS), in free-ranging marine mammals exposed to sequences of airgun pulses during realistic field conditions. Current NMFS policy regarding exposure of marine mammals to high-level sounds is that cetaceans and pinnipeds should not be exposed to impulsive sounds ≥180 and 190 dB re 1 μPa_{rms}, respectively (NMFS 2000). Those criteria have been used in establishing the safety (shut-down) radii planned for numerous seismic surveys conducted under U.S. jurisdiction. However, those criteria were established before there was any information about the minimum received levels of sounds necessary to cause auditory impairment in marine mammals. As discussed below,

- the 180-dB criterion for cetaceans is probably precautionary for at least some species including bottlenose dolphin and beluga, i.e., lower than necessary to avoid temporary auditory impairment let alone permanent auditory injury.
- the 180-dB criterion may not be precautionary with regard to TTS in some other cetacean species, including the harbor porpoise. Likewise, the 190-dB criterion for pinnipeds may not be precautionary for all pinnipeds, although for pinnipeds the underlying data are indirect and quite variable among species.
- the likelihood of TTS (and probably also PTS) upon exposure to high-level sound may be better correlated with the amount of acoustic energy received by the animal, measured by the cumulative sound exposure level (SEL) in dB re 1 $\mu Pa^2 \cdot s$, than it is with maximum received RMS pressure level in dB re 1 $\mu Pa_{rms.}$. SEL allows for exposure duration and/or number of exposures; the maximum rms level does not. Thus, the current U.S. criteria may not be expressed in the most appropriate acoustic units.
- low and moderate degrees of TTS, up to at least 30 dB of elevation of the threshold, are not considered injury and do not constitute "Level A harassment" in U.S. MMPA terminology. Beyond that level, TTS may grade into PTS (Le Prell 2012).
- the minimum sound level necessary to cause permanent hearing impairment ("Level A harassment") is higher, by a variable and generally unknown amount, than the level that induces barely-detectable TTS.

- the level associated with the onset of TTS is often considered to be a level below which there is no danger of permanent damage. The actual PTS threshold is likely to be well above the level causing onset of TTS (Southall et al. 2007).

Recommendations for new science-based sound exposure criteria for marine mammals, frequency-weighting procedures, and related matters were published by Southall et al. (2007). Those recommendations were never formally adopted by NMFS for use in regulatory processes and during mitigation programs associated with seismic surveys, although some aspects of the recommendations have been taken into account in certain EISs and small-take authorizations. NMFS recently proposed new procedures taking at least some of the Southall et al. recommendations into account (NOAA 2013). The new sound exposure criteria for marine mammals will account for the now additional scientific data on TTS, the expected offset between the TTS and PTS thresholds, differences in the acoustic frequencies to which different marine mammal groups are sensitive (e.g., M-weighting or generalized frequency weightings for various groups of marine mammals, allowing for their functional bandwidths), and other relevant factors.

Nowacek et al. (2013) 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 monitoring and mitigation measures that are now often implemented during seismic survey projects 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. In addition, many cetaceans and (to a limited degree) pinnipeds 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 will reduce or (most likely) avoid the possibility of hearing impairment.

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 include stress, neurological effects, bubble formation, and other types of organ or tissue damage. It is possible that some marine mammal species (i.e., beaked whales) may be especially susceptible to injury and/or stranding when exposed to strong pulsed sounds. The following subsections summarize available data on sound-induced hearing impairment and non-auditory physical effects.

1.6.1 Temporary Threshold Shift (TTS)

TTS is the mildest form of hearing impairment that can occur during exposure to a strong sound (Kryter 1985). While experiencing TTS, the hearing threshold rises and a sound must be stronger in order to be heard. It is a temporary phenomenon, and (especially when mild) is not considered to represent physical damage or "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. Recent research has shown that sound exposure can cause cochlear neural degeneration, even when threshold shifts and hair cell damage are reversible (Liberman 2013). 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).

The magnitude of TTS depends on the level and duration of sound exposure, and to some degree on frequency, among other considerations (Kryter 1985; Richardson et al. 1995; Southall et al. 2007). For sound exposures at or somewhat above the TTS threshold, hearing sensitivity recovers rapidly after exposure to the sound ends. Extensive studies on terrestrial mammal hearing in air show that TTS can last from minutes or hours to (in cases of strong TTS) days. More limited data from odontocetes and

pinnipeds show similar patterns (e.g., Mooney et al. 2009a,b; Finneran et al. 2010a). However, none of the published data concern TTS elicited by exposure to multiple pulses of sound during operational seismic surveys (Southall et al. 2007).

Toothed Whales

There are empirical data on the sound exposures that elicit onset of TTS in captive bottlenose dolphins, belugas, harbor porpoise, and finless porpoise. The majority of these data concern non-impulse sound, but there are some limited published data concerning TTS onset upon exposure to a single pulse of sound from a watergun (Finneran et al. 2002) and multiple pulses from an airgun (Finneran et al. 2011; Schlundt et al. 2013). A detailed review of all TTS data from marine mammals can be found in Southall et al. (2007). The following summarizes some of the key results from odontocetes.

Recent information corroborates earlier expectations that the effect of exposure to strong transient sounds is closely related to the total amount of acoustic energy that is received. Finneran et al. (2005) examined the effects of tone duration on TTS in bottlenose dolphins. Bottlenose dolphins were exposed to 3 kHz tones (non-impulsive) for periods of 1, 2, 4 or 8 s, with hearing tested at 4.5 kHz. For 1-s exposures, TTS occurred with SELs of 197 dB, and for exposures >1 s, SEL >195 dB resulted in TTS (SEL is equivalent to energy flux, in dB re 1 $\mu Pa^2 \cdot s$). At an SEL of 195 dB, the mean TTS (4 min after exposure) was 2.8 dB. Finneran et al. (2005) suggested that an SEL of 195 dB is the likely threshold for the onset of TTS in dolphins and belugas exposed to tones of durations 1–8 s (i.e., TTS onset occurs at a near-constant SEL, independent of exposure duration). That implies that, at least for non-impulsive tones, a doubling of exposure time results in a 3 dB lower TTS threshold.

The assumption that, in marine mammals, the occurrence and magnitude of TTS is a function of cumulative acoustic energy (SEL) is probably an oversimplification (Finneran 2012). Frequency, duration of the exposure, and occurrence of gaps within the exposure can also influence the auditory effect on marine mammals (Kastak et al. 2005; Mooney et al. 2009a; Finneran and Schlundt 2010, 2011, 2013; Finneran et al. 2010a,b; Popov et al. 2011, 2013a; Finneran 2012; Kastelein et al. 2012a,b; 2013a,b, 2014). For example, Kastak et al. (2005) reported preliminary evidence from pinnipeds that, for prolonged non-impulse sound, higher SELs were required to elicit a given TTS if exposure duration was short than if it was longer, i.e., the results were not fully consistent with an equal-energy model to predict TTS onset. Mooney et al. (2009a) showed this in a bottlenose dolphin exposed to octave-band non-impulse sound ranging from 4 to 8 kHz at SPLs of 130 to 178 dB re 1 μPa for periods of 1.88 to 30 min. Similar to the study by Kastak et al. (2005), higher SELs were required to induce a given TTS if exposure duration was short than if it was longer. Exposure of the aforementioned bottlenose dolphin to a sequence of brief sonar signals showed that, with those brief (but non-impulse) sounds, the received energy (SEL) necessary to elicit TTS was higher than was the case with exposure to the more prolonged octave-band noise (Mooney et al. 2009b). Those authors concluded that, when using (non-impulse) acoustic signals of duration ~0.5 s, SEL must be at least 210–214 dB re 1 $\mu Pa^2 \cdot s$ to induce TTS in the bottlenose dolphin. 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.

On the other hand, the TTS threshold for odontocetes exposed to a single impulse from a watergun (Finneran et al. 2002) appeared to be somewhat lower than for exposure to non-impulse sound. This was expected, based on evidence from terrestrial mammals showing that broadband pulsed sounds with rapid

rise times have greater auditory effect than do non-impulse sounds (Southall et al. 2007). The received energy level of a single seismic pulse that caused the onset of mild TTS in the beluga, as measured without frequency weighting, was ~186 dB re 1 $\mu Pa^2 \cdot s$ or 186 dB SEL (Finneran et al. 2002).[7] The rms level of an airgun pulse (in dB re 1 μPa measured over the duration of the pulse) is typically 10–15 dB higher than the SEL for the same pulse when received within a few kilometres of the airguns. Thus, a single airgun pulse might need to have a received level of ~196–201 dB re 1 μPa_{rms} in order to produce brief, mild TTS. Exposure to several strong sound pulses from an airgun source that each has a flat-weighted received level near 190 dB_{rms} (175–180 dB SEL) could result in cumulative exposure of ~186 dB SEL (flat-weighted) or ~183 dB SEL (M_{mf}-weighted), and thus slight TTS in a small odontocete. That assumes that the TTS threshold upon exposure to multiple pulses is (to a first approximation) a function of the total received pulse energy, without allowance for any recovery between pulses. However, recent data 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). Schlundt et al. (2013) reported that the potential for seismic surveys using airguns to cause auditory effects on dolphins may be lower than previously thought. Based on behavioral tests, Finneran et al. (2011) and Schlundt et al. (2013) reported no measurable TTS in bottlenose dolphins after exposure to 10 impulses from a seismic airgun with a cumulative SEL of ~195 dB re 1 $\mu Pa^2 \cdot s$; results from AEP measurements were more variable (Schlundt et al. 2013).

The conclusion that the TTS threshold is higher for non-impulse sound than for impulse sound is somewhat speculative. The available TTS data for a beluga whale exposed to impulse sound are extremely limited, and the TTS data from the beluga whale and bottlenose dolphin exposed to non-pulse sound pertain to sounds at 3 kHz and above. Follow-on work has 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, 2013; Finneran 2012). When beluga whales were exposed to fatiguing noise with sound levels of 165 dB re 1 μPa for durations of 1 to 30 min at frequencies of 11.2 to 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. 2013a). Popov et al. (2013b) also 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 marinemammals (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).

The above TTS information for odontocetes is primarily derived from studies on the bottlenose dolphin and beluga; there have been no studies of narwhal hearing impairment attributable to airgun sounds. However, there have been several studies on TTS in porpoise (e.g., Lucke et al. 2009; Popov et al. 2011; Kastelein et al. 2012a, 2013a,b, 2014) which indicate that received levels that elicit onset of TTS are lower in porpoise than for other odontocetes. Lucke et al. (2009) exposed a harbor porpoise to single pulses from a small (20 in^3) airgun, and auditory evoked potential methods were used to test the animal's hearing sensitivity at frequencies of 4, 32, or 100 kHz after each exposure. Based on the measurements at 4 kHz, TTS occurred upon exposure to one airgun pulse with received level ~200 dB re 1 $\mu Pa_{pk\text{-}pk}$ or an

[7] If the low-frequency components of the watergun sound used in the experiments of Finneran et al. (2002) are downweighted as recommended by Southall et al. (2007) using their M_{mf}-weighting curve, the effective exposure level for onset of mild TTS was 183 dB re 1 $\mu Pa^2 \cdot s$ (Southall et al. 2007).

SEL of 164.3 dB re 1 μPa^2·s. Kastelein et al. (2012a) exposed a harbor porpoise to octave band noise centred at 4 kHz for extended periods of time. A 6 dB TTS occurred with a SEL of 163 dB and 172 dB for low-intensity sound and medium-intensity sound, respectively; high-intensity sound caused a 9 dB TTS at a SEL of 175 dB (Kastelein et al. 2012a). Kastelein et al. (2013b) exposed a harbor porpoise to a long, continuous 1.5 kHz tone, which induced a 14 dB TTS with a total SEL of 190 dB. Popov et al. (2011) 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 centred at 45 kHz with an SEL of 163 dB.

Based on these studies with porpoises, it is inappropriate to assume that onset of TTS occurs at similar received levels in all odontocetes (*cf.* Southall et al. 2007). Some cetaceans may incur TTS at lower sound exposures than are necessary to elicit TTS in the beluga or bottlenose dolphin. Tougaard et al. (2015) suggested an exposure limit for TTS as an SEL of 100–110 dB above the porpoise pure tone hearing threshold at a specific ferquency; they also suggested an exposure limit of $L_{\text{eq-fast}}$ (rms average over the duration of the pulse) of 45 dB above the hearing threshold for behavioral responses (i.e., negative phonotaxis). In addition, M-weighting may not be appropriate for harbor porpoise (Wensveen et al. 2014; Tougaard et al. 2015); thus, Wensveen et al. (2014) developed six auditory weighting functions for harbor porpoise that may be useful in predicting TTS onset.

Insofar as we are aware, there are no published data confirming that the auditory effect of a sequence of airgun pulses received by an odontocete is a function of their cumulative energy. Southall et al. (2007) consider that to be a reasonable, but probably somewhat precautionary, assumption. It is precautionary because, based on data from terrestrial mammals, one would expect that a given energy exposure would have somewhat less effect if separated into discrete pulses, with potential opportunity for partial auditory recovery between pulses. However, as yet there has been little study of the rate of recovery from TTS in marine mammals, and in humans and other terrestrial mammals the available data on recovery are quite variable. Southall et al. (2007) concluded that—until relevant data on recovery are available from marine mammals—it is appropriate not to allow for any assumed recovery during the intervals between pulses within a pulse sequence.

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., Erbe and King 2009; 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 even though that energy is received in multiple pulses separated by gaps. The lack of data on the exposure levels necessary to cause TTS in toothed whales when the signal is a series of pulsed sounds, separated by silent periods, remains a data gap, as is the lack of published data on TTS in odontocetes other than the beluga, bottlenose dolphin, harbor porpoise, and Yangtze finless porpoise.

Baleen Whales

There are no data, direct or indirect, on levels or properties of sound that are required to induce TTS in any baleen whale. The frequencies to which mysticetes are most sensitive are assumed to be lower than those to which odontocetes are most sensitive, and natural background noise levels at those low frequencies tend to be higher. As a result, auditory thresholds of baleen whales within their frequency band of best hearing are believed to be higher (less sensitive) than are those of odontocetes at their best frequencies (Clark and Ellison 2004). Based on this, Southall et al. (2007) suspected that

received levels causing TTS onset may also be higher in mysticetes, although Wood et al. (2012) suggested that received levels that cause hearing impairment in baleen whales may be lower. However, based on preliminary simulation modeling that attempted to allow for various uncertainties in assumptions and variability around population means, Gedamke et al. (2011) suggested that some baleen whales whose closest point of approach to a seismic vessel is 1 km or more could experience TTS.

In practice during seismic surveys, few if any cases of TTS are expected given the strong likelihood that baleen whales would avoid the approaching airguns (or vessel) before being exposed to levels high enough for there to be any possibility of TTS (see above for evidence concerning avoidance responses by baleen whales). This assumes that the ramp-up (soft-start) procedure is used when commencing airgun operations, to give whales near the vessel the opportunity to move away before they are exposed to sound levels that might be strong enough to elicit TTS. As discussed earlier, single-airgun experiments with bowhead, gray, and humpback whales show that those species do tend to move away when a single airgun starts firing nearby, which simulates the onset of a ramp up.

Pinnipeds

In pinnipeds, TTS thresholds associated with exposure to brief pulses (single or multiple) of underwater sound have not been measured. Two California sea lions did not incur TTS when exposed to single brief pulses with received levels of ~178 and 183 dB re 1 μPa_{rms} and total acoustic energy of 161 and 163 dB re 1 $\mu Pa^2 \cdot s$ (Finneran et al. 2003). However, initial evidence from exposures to non-pulses 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). Kastak et al. (2005) reported that the amount of threshold shift increased with increasing SEL in a California sea lion and harbor seal. They noted that, for non-impulse sound, doubling the exposure duration from 25 to 50 min (i.e., a +3 dB change in SEL) had a greater effect on TTS than an increase of 15 dB (95 vs. 80 dB) in exposure level. Mean threshold shifts ranged from 2.9–12.2 dB, with full recovery within 24 hr (Kastak et al. 2005). Kastak et al. (2005) suggested that, for non-impulse sound, SELs resulting in TTS onset in three species of pinnipeds may range from 183 to 206 dB re 1 $\mu Pa^2 \cdot s$, depending on the absolute hearing sensitivity. Kastak et al. (2008) exposed a harbor seal to an underwater pure tone at 4.1 kHz for 60 s (SEL of 202 dB re 1 μPa^2) and reported an initial threshold shift in excess of 50 dB upon a second exposure to the sound. Kastelein et al. (2012b) exposed two harbor seals to octave-band white noise centred at 4 kHz at three mean received SPLs of 124, 136, and 148 dB re 1 µPa; TTS >2.5 dB was induced at SELs 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. (2013a) 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 hr induced a 44 dB TTS.

As noted above for odontocetes, it is expected that—for impulse as opposed to non-impulse sound—the onset of TTS would occur at a lower cumulative SEL given the assumed greater auditory effect of broadband impulses with rapid rise times. The threshold for onset of mild TTS upon exposure of a harbor seal to impulse sounds has been estimated indirectly as being an SEL of ~171 dB re 1 $\mu Pa^2 \cdot s$ (Southall et al. 2007). That would be approximately equivalent to a single pulse with received level ~181–186 dB re 1 μPa_{rms}, or a series of pulses for which the highest rms values are a few dB lower.

At least for non-impulse sounds, TTS onset occurs at appreciably higher received levels in California sea lions and northern elephant seals than in harbor seals (Kastak et al. 2005). Thus, the former two species would presumably need to be closer to an airgun array than would a harbor seal before TTS is

a possibility. Insofar as we are aware, there are no data to indicate whether the TTS thresholds of other pinniped species are more similar to those of the harbor seal or to those of the two less-sensitive species.

Likelihood of Incurring TTS

Most cetaceans show some degree of avoidance of seismic vessels operating an airgun array (see above). It is unlikely that these cetaceans would be exposed to airgun pulses at a sufficiently high level for a sufficiently long period to cause more than mild TTS, given the relative movement of the vessel and the marine mammal. TTS would be more likely in any odontocetes that bow- or wake-ride or otherwise linger near the airguns. However, while bow- or wake-riding, odontocetes would be at the surface and thus not exposed to strong sound pulses given the pressure-release and Lloyd Mirror effects at the surface. But if bow- or wake-riding animals were to dive intermittently near airguns, they would be exposed to strong sound pulses, possibly repeatedly.

If some cetaceans did incur mild or moderate TTS through exposure to airgun sounds in this manner, this would very likely be a temporary and reversible phenomenon. However, even a temporary reduction in hearing sensitivity could be deleterious in the event that, during that period of reduced sensitivity, a marine mammal needed its full hearing sensitivity to detect approaching predators, or for some other reason.

Some pinnipeds show avoidance reactions to airguns, but their avoidance reactions are generally not as strong or consistent as those of cetaceans. Pinnipeds occasionally seem to be attracted to operating seismic vessels. There are no specific data on TTS thresholds of pinnipeds exposed to single or multiple low-frequency pulses. However, given the indirect indications of a lower TTS threshold for the harbor seal than for odontocetes exposed to impulse sound (see above), it is possible that some pinnipeds close to a large airgun array could incur TTS.

NMFS (1995, 2000) concluded that cetaceans should not be exposed to pulsed underwater noise at received levels >180 dB re 1 μPa_{rms}. The corresponding limit for pinnipeds has been set by NMFS at 190 dB, although the HESS Team (HESS 1999) recommended a 180-dB limit for pinnipeds in California. The 180 and 190 dB re 1 μPa_{rms} levels have not been considered to be the levels above which TTS might occur. Rather, they were the received levels above which, in the view of a panel of bioacoustics specialists convened by NMFS before TTS measurements for marine mammals started to become available, one could not be certain that there would be no injurious effects, auditory or otherwise, to marine mammals. As summarized above, data that are now available imply that TTS is unlikely to occur in various odontocetes (and probably mysticetes as well) unless they are exposed to a sequence of several airgun pulses stronger than 190 dB re 1 μPa_{rms}. On the other hand, for the harbor seal, harbor porpoise, and perhaps some other species, TTS may occur upon exposure to one or more airgun pulses whose received level equals the NMFS "do not exceed" value of 190 dB re 1 μPa_{rms}. That criterion corresponds to a single-pulse SEL of 175–180 dB re 1 $\mu Pa^2 \cdot s$ in typical conditions, whereas TTS is suspected to be possible in harbour seals and harbor porpoises with a cumulative SEL of ~171 and ~164 dB re 1 $\mu Pa^2 \cdot s$, respectively.

It has been shown that most large whales and many smaller odontocetes (especially the harbor porpoise) show at least localized avoidance of ships and/or seismic operations (see above). Even when avoidance is limited to the area within a few hundred metres of an airgun array, that should usually be sufficient to avoid TTS based on what is currently known about thresholds for TTS onset in cetaceans. In addition, ramping up airgun arrays, which is standard operational protocol for many seismic operators, should allow cetaceans near the airguns at the time of startup (if the sounds are aversive) to move away

from the seismic source and to avoid being exposed to the full acoustic output of the airgun array (see above). Thus, most baleen whales likely will not be exposed to high levels of airgun sounds provided the ramp-up procedure is applied. Likewise, many odontocetes close to the trackline are likely to move away before the sounds from an approaching seismic vessel become sufficiently strong for there to be any potential for TTS or other hearing impairment. Therefore, there is little potential for baleen whales or odontocetes that show avoidance of ships or airguns to be close enough to an airgun array to experience TTS. In the event that a few individual cetaceans did incur TTS through exposure to strong airgun sounds, this is a temporary and reversible phenomenon unless the exposure exceeds the TTS-onset threshold by a sufficient amount for PTS to be incurred (see below). If TTS but not PTS were incurred, it would most likely be mild, in which case recovery is expected to be quick (probably within minutes).

1.6.2 Permanent Threshold Shift (PTS)

When PTS occurs, there is physical damage to the sound receptors in the ear. In some cases, there can be total or partial deafness, whereas in other cases, the animal has an impaired ability to hear sounds in specific frequency ranges (Kryter 1985). 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 they have very short rise times. (Rise time is the interval required for sound pressure to increase from the baseline pressure to peak pressure.)

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 strong possibility that some mammals close to an airgun array might incur at least mild TTS (see above), 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. 372*ff*; 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).

Relationships between TTS and PTS thresholds have not been studied in marine mammals, but are assumed to be similar to those in humans and other terrestrial mammals (Southall et al. 2007). Based on data from terrestrial mammals, a precautionary assumption is that the PTS threshold for impulse sounds (such as airgun pulses as received close to the source) is <u>at least</u> 6 dB higher than the TTS threshold on a peak-pressure basis, and probably >6 dB higher (Southall et al. 2007). The low-to-moderate levels of TTS that have been induced in captive odontocetes and pinnipeds during controlled studies of TTS have been confirmed to be temporary, with no measurable residual PTS (Kastak et al. 1999; Schlundt et al. 2000; Finneran et al. 2002, 2005; Nachtigall et al. 2003, 2004). However, very prolonged exposure to sound strong enough to elicit TTS, or shorter-term exposure to sound levels well above the TTS threshold, can cause PTS, at least in terrestrial mammals (Kryter 1985). When a harbor seal was exposed to an underwater pure tone at 4.1 kHz for 60 s (SEL of 202 dB re 1 μPa^2), an initial threshold shift in excess of 50 dB was reported upon the second exposure to the sound; a possible permanent threshold shift of 7–10 dB was still evident two months after the exposure (Kastak et al. 2008). In terrestrial mammals, the received sound level from a single non-impulsive sound exposure must be far above the TTS threshold for any risk of permanent hearing damage (Kryter 1994; Richardson et al. 1995; Southall et al. 2007). However, there is special concern about strong sounds whose pulses have very rapid rise times. In terrestrial mammals, there are situations when pulses with rapid rise times (e.g., from explosions) can

result in PTS even though their peak levels are only a few dB higher than the level causing slight TTS. The rise time of airgun pulses is fast, but not as fast as that of an explosion.

Some factors that contribute to onset of PTS, at least in terrestrial mammals, are as follows:

- exposure to single very intense sound,
- fast rise time from baseline to peak pressure,
- repetitive exposure to intense sounds that individually cause TTS but not PTS, and
- recurrent ear infections or (in captive animals) exposure to certain drugs.

Cavanagh (2000) reviewed the thresholds used to define TTS and PTS. Based on this review and SACLANT (1998), it is reasonable to assume that PTS might occur at a received sound level 20 dB or more above that inducing mild TTS. However, for PTS to occur at a received level only 20 dB above the TTS threshold, the animal probably would have to be exposed to a strong sound for an extended period, or to a strong sound with rather rapid rise time. Kastelein et al. (2013a) suggested that for a harbor seal exposed to octave-band white noise centred 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.

Southall et al. (2007) estimated that received levels would need to exceed the TTS threshold by at least 15 dB, on an SEL basis, for there to be risk of PTS. Thus, for cetaceans exposed to a sequence of sound pulses, they estimate that the PTS threshold might be an M-weighted SEL (for the sequence of received pulses) of ~198 dB re 1 $\mu Pa^2 \cdot s$ (15 dB higher than the M_{mf}-weighted TTS threshold, in a beluga, for a watergun impulse). Additional assumptions had to be made to derive a corresponding estimate for pinnipeds, as the only available data on TTS-thresholds in pinnipeds pertained to non-impulse sound (see above). Southall et al. (2007) estimated that the PTS threshold could be a cumulative M_{pw}-weighted SEL of ~186 dB re 1 $\mu Pa^2 \cdot s$ in the case of a harbor seal exposed to impulse sound. The PTS threshold for the California sea lion and northern elephant seal would probably be higher given the higher TTS thresholds in those species. Southall et al. (2007) also noted that, regardless of the SEL, there is concern about the possibility of PTS if a cetacean or pinniped received one or more pulses with peak pressure exceeding 230 or 218 dB re 1 μPa, respectively. Thus, PTS might be expected upon exposure of cetaceans to <u>either</u> SEL ≥198 dB re 1 $\mu Pa^2 \cdot s$ <u>or</u> peak pressure ≥230 dB re 1 μPa. Corresponding proposed dual criteria for pinnipeds (at least harbor seals) are ≥186 dB SEL and ≥ 218 dB peak pressure (Southall et al. 2007).

These estimates are all first approximations, given the limited underlying data, numerous assumptions, and species differences. Also, data have been published subsequent to Southall et al. (2007) indicating that, at least for non-pulse sounds, the "equal energy" model is not be entirely correct—TTS and presumably PTS thresholds may depend somewhat on the duration over which sound energy is accumulated, the frequency of the sound, whether or not there are gaps, and probably other factors (Ketten 1994, 2012). PTS effects may also be influenced strongly by the health of the receiver's ear.

As described above for TTS, in estimating the amount of sound energy required to elicit the onset of TTS (and PTS), it is assumed that the auditory effect of a given cumulative SEL from a series of pulses is the same as if that amount of sound energy were received as a single strong sound. There are no data from marine mammals concerning the occurrence or magnitude of a potential partial recovery effect between pulses. In deriving the estimates of PTS (and TTS) thresholds quoted here, Southall et al. (2007) made the precautionary assumption that no recovery would occur between pulses.

The TTS section (above) concludes that exposure to several strong seismic pulses that each have flat-weighted received levels near 190 dB re 1 μPa_{rms} (175–180 dB re 1 $\mu Pa^2 \cdot s$ SEL) could result in

cumulative exposure of ~186 dB SEL (flat-weighted) or ~183 dB SEL (M_{mf}-weighted), and thus slight TTS in a small odontocete. Allowing for the assumed 15 dB offset between PTS and TTS thresholds, expressed on an SEL basis, exposure to several strong seismic pulses that each have flat-weighted received levels near 205 dB_{rms} (190-195 dB SEL) could result in cumulative exposure of ~198 dB SEL (M_{mf}-weighted), and thus slight PTS in a small odontocete. However, the levels of successive pulses that will be received by a marine mammal that is below the surface as a seismic vessel approaches, passes and moves away will tend to increase gradually and then decrease gradually, with periodic decreases superimposed on this pattern when the animal comes to the surface to breathe. To estimate how close an odontocete's CPA distance would have to be for the cumulative SEL to exceed 198 dB SEL (M_{mf}-weighted), 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., Erbe and King 2009).

It is unlikely that an odontocete would remain close enough to a large airgun array for sufficiently long to incur PTS. There is some concern about bowriding odontocetes, but for animals at or near the surface, auditory effects are reduced by Lloyd's mirror and surface release effects. The presence of the vessel between the airgun array and bow-riding odontocetes could also, in some but probably not all cases, reduce the levels received by bow-riding animals (e.g., Gabriele and Kipple 2009). The TTS (and thus PTS) thresholds of baleen whales are unknown but, as an interim measure, assumed to be no lower than those of odontocetes. Also, baleen whales generally avoid the immediate area around operating seismic vessels, so it is unlikely that a baleen whale could incur PTS from exposure to airgun pulses. The TTS (and thus PTS) thresholds of some pinnipeds (e.g., harbor seal) as well as the harbor porpoise may be lower (Kastak et al. 2005; Southall et al. 2007; Lucke et al. 2009; Kastelein et al. 2012a,b, 2013a,b, 2014). If so, TTS and potentially PTS may extend to a somewhat greater distance for those animals. Again, Lloyd's mirror and surface release effects will ameliorate the effects for animals at or near the surface.

Although it is unlikely that airgun operations during most seismic surveys would cause PTS in many marine mammals, caution is warranted given

- the limited knowledge about sound-induced hearing damage in marine mammals, particularly baleen whales, pinnipeds, and sea otters;
- the seemingly greater susceptibility of certain species (e.g., harbor porpoise and harbor seal) to TTS and presumably also PTS; and
- the lack of knowledge about TTS and PTS thresholds in many species, including various species closely related to the harbor porpoise and harbor seal.

The avoidance reactions of many marine mammals, along with commonly-applied monitoring and mitigation measures (visual and passive acoustic monitoring, ramp ups, and power downs or shut downs when mammals are detected within or approaching the "safety radii"), would reduce the already-low probability of exposure of marine mammals to sounds strong enough to induce PTS.

1.6.3 Strandings and Mortality

Marine mammals close to underwater detonations of high explosives can be killed or severely injured, and the auditory organs are especially susceptible to injury (Ketten et al. 1993; Ketten 1995). However, explosives are no longer used in marine waters for commercial seismic surveys or (with rare exceptions) for seismic research; they have been replaced by airguns and other non-explosive sources.

Airgun pulses are less energetic and have slower rise times, and there is no specific evidence that they can cause serious injury, death, or stranding even in the case of large airgun arrays. However, the association of mass strandings of beaked whales with naval exercises and, in one case, a seismic survey (Malakoff 2002; Cox et al. 2006), has raised the possibility that beaked whales exposed to strong "pulsed" sounds may be especially susceptible to injury and/or behavioral reactions that can lead to stranding (e.g., Hildebrand 2005; Southall et al. 2007). Hildebrand (2005) reviewed the association of cetacean strandings with high-intensity sound events and found that deep-diving odontocetes, primarily beaked whales, were by far the predominant (95%) cetaceans associated with these events, with 2% mysticete whales (minke). However, as summarized below, there is no definitive evidence that airguns can lead to injury, strandings, or mortality even for marine mammals in close proximity to large airgun arrays.

Specific sound-related processes that lead to strandings and mortality are not well documented, but may include (1) swimming in avoidance of a sound into shallow water; (2) a change in behavior (such as a change in diving behavior that might contribute to tissue damage, gas bubble formation, hypoxia, cardiac arrhythmia, hypertensive hemorrhage or other forms of trauma; (3) a physiological change such as a vestibular response leading to a behavioral change or stress-induced hemorrhagic diathesis, leading in turn to tissue damage; and (4) tissue damage directly from sound exposure, such as through acoustically mediated bubble formation and growth or acoustic resonance of tissues. Some of these mechanisms are unlikely to apply in the case of impulse sounds. However, there are increasing indications that gas-bubble disease (analogous to "the bends"), induced in supersaturated tissue by a behavioral response to acoustic exposure, could be a pathologic mechanism for the strandings and mortality of some deep-diving cetaceans exposed to sonar. The evidence for this remains circumstantial and associated with exposure to naval mid-frequency sonar, not seismic surveys (Cox et al. 2006; Southall et al. 2007; Kvadsheim et al. 2012).

Seismic pulses and mid-frequency sonar signals are quite different, and some mechanisms by which sonar sounds have been hypothesized to affect beaked whales are unlikely to apply to airgun pulses. Sounds produced by airgun arrays are broadband impulses with most of the energy below 1 kHz. Typical military mid-frequency sonars emit non-impulse sounds at frequencies of 2–10 kHz, generally with a relatively narrow bandwidth at any one time (though the frequency may change over time). Thus, it is not appropriate to assume that the effects of seismic surveys on beaked whales or other species would be the same as the apparent effects of military sonar. For example, resonance effects (Gentry 2002) and acoustically-mediated bubble-growth (Crum et al. 2005) are implausible in the case of exposure to broadband airgun pulses. Nonetheless, evidence that sonar signals can, in special circumstances, lead (at least indirectly) to physical damage and mortality (e.g., Balcomb and Claridge 2001; NOAA and USN 2001; Jepson et al. 2003; Fernández et al. 2004, 2005; Hildebrand 2005; Cox et al. 2006) suggests that caution is warranted when dealing with exposure of marine mammals to any high-intensity "pulsed" sound. One of the hypothesized mechanisms by which naval sonars lead to strandings might, in theory, also apply to seismic surveys: If the strong sounds sometimes cause deep-diving species to alter their surfacing–dive cycles in a way that causes bubble formation in tissue, that hypothesized mechanism might apply to seismic surveys as well as mid-frequency naval sonars. However, there is no specific evidence of this upon exposure to airgun pulses.

There is no conclusive evidence of cetacean strandings or deaths at sea as a result of exposure to seismic surveys. However, 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. Additionally, a few cases of strandings in the general area where a seismic survey was ongoing have led

to speculation concerning a possible link between seismic surveys and strandings (e.g., Castellote and Llorens 2013). • Suggestions that there was a link between seismic surveys and strandings of humpback whales in Brazil (Engel et al. 2004) were not well founded (IAGC 2004; IWC 2007). • In Sept. 2002, there was a stranding of two Cuvier's beaked whales in the Gulf of California, Mexico, when the L-DEO seismic vessel R/V *Maurice Ewing* was operating a 20-airgun, 8490-in^3 airgun array in the general area. The evidence linking the stranding to the seismic survey was inconclusive and not based on any physical evidence (Hogarth 2002; Yoder 2002). The ship was also operating its multibeam echosounder at the same time, but this had much less potential than the aforementioned naval sonars to affect beaked whales, given its downward-directed beams, much shorter pulse durations, and lower duty cycle. Nonetheless, the Gulf of California incident plus the beaked whale strandings near naval exercises involving use of mid-frequency sonar suggest a need for caution in conducting seismic surveys in areas occupied by beaked whales until more is known about effects of seismic surveys on those species (Hildebrand 2005).

1.6.4 Non-Auditory Physiological Effects

Based on evidence from terrestrial mammals and humans, sound is a potential source of stress (Wright and Kuczaj 2007; Wright et al. 2007a,b, 2009, 2011). However, almost no information is available on sound-induced stress in marine mammals, or on its potential (alone or in combination with other stressors) to affect the long-term well-being or reproductive success of marine mammals (Fair and Becker 2000; Hildebrand 2005; Wright et al. 2007a,b). Such long-term effects, if they occur, would be mainly associated with chronic noise exposure, which is characteristic of some seismic surveys and exposure situations (McCauley et al. 2000a:62*ff*; Nieukirk et al. 2012) but not of some others.

Available data on potential stress-related impacts of anthropogenic noise on marine mammals are extremely limited, and additional research on this topic is needed. ***(1)*** Romano et al. (2004) examined the effects of single underwater impulse sounds from a seismic water gun (source level up to 228 dB re 1 μPa · m_{p-p}) and single short-duration pure tones (sound pressure level up to 201 dB re 1 μPa) on the nervous and immune systems of a beluga and a bottlenose dolphin. They found that neural-immune changes to noise exposure were minimal. Although levels of some stress-released substances (e.g., catecholamines) changed significantly with exposure to sound, levels returned to baseline after 24 hr. ***(2)*** During playbacks of recorded drilling noise to four captive beluga whales, Thomas et al. (1990) found no changes in blood levels of stress-related hormones. Long-term effects were not measured, and no short-term effects were detected. ***(3)*** 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.

Aside from stress, other types of physiological effects that might, in theory, be involved in beaked whale strandings upon exposure to naval sonar (Cox et al. 2006), such as resonance and gas bubble formation, have not been demonstrated and are not expected upon exposure to airgun pulses (see preceding subsection). If seismic surveys disrupt diving patterns of deep-diving species, this might perhaps result in bubble formation and a form of "the bends", as speculated to occur in beaked whales exposed to sonar. However, there is no specific evidence that exposure to airgun pulses has this effect.

In summary, very little is known about the potential for seismic survey sounds (or other types of strong underwater sounds) to cause non-auditory physiological effects in marine mammals. Such effects, if they occur at all, would presumably be limited to short distances and to activities that extend over a prolonged period. The available data do not allow identification of a specific exposure level above which

non-auditory effects can be expected (Southall et al. 2007), or any meaningful quantitative predictions of the numbers (if any) of marine mammals that might be affected in these ways.

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