Environmental Assessment of a Marine Geophysical Survey by the R/V *Endeavor* in the Northwest Atlantic Ocean, August 2009

Prepared for

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ABSTRACT

Rice University (Rice), Department of Earth Sciences, plans to conduct a low-energy seismic survey in the Northwest Atlantic Ocean (NWA) during August 2009 with research funding from the National Science Foundation (NSF). The survey will occur along the continental shelf southeast of the island of Martha's Vineyard (MV), Massachusetts (MA), and will also likely include Nantucket Sound. The survey will take place in water depths ranging from ~20 to ~125 m. The seismic study will use two generator-injector (GI) guns with a total discharge volume of ~90 in^3.

NSF, as the funding and action agency, has a mission to "promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense…". The proposed seismic survey is part of a research proposal recommended for funding by an expert review panel. Vast amounts of freshwater are sequestered under the continental shelf off North America, South America, Europe, and Asia. The proposed survey will provide data integral to advancing a scientific understanding of the distribution and abundance of freshwater available off the U.S. northeast coast, potentially providing a valuable resource to nearby population centers.

Rice is requesting an Incidental Harassment Authorization (IHA) from the National Marine Fisheries Service (NMFS) to authorize the incidental, i.e., not intentional, harassment of small numbers of marine mammals should this occur during the seismic survey. The information in this Environmental Assessment (EA) supports the IHA application process and provides information on additional marine species, including birds, sea turtles, and fish that are listed under the U.S. Endangered Species Act (ESA) and Essential Fish Habitat (EFH). The EA addresses the requirements of the National Environmental Policy Act (NEPA). Alternatives addressed in this EA consist of a corresponding program at a different time, along with issuance of an associated IHA; and the no action alternative, with no IHA and no seismic survey.

Numerous species of cetaceans and pinnipeds inhabit the NWA. Several of these species are listed as ***endangered*** under the ESA, including the North Atlantic right, humpback, sei, fin, blue, and sperm whales. Other species of special concern that could occur in the study area are the ***endangered*** leatherback and Kemp's ridley turtles, the ***threatened*** loggerhead and green turtles, and the ***endangered*** roseate tern. The ***endangered*** Atlantic salmon and shortnose sturgeon may also occur at low densities in or near the study area.

Potential impacts of the seismic survey on the environment would be primarily a result of the operation of the two GI guns. A dual-frequency echosounder and a sub-bottom profiler (SBP) will also be operated. Impacts would be associated with increased underwater noise, which may result in avoidance behavior of marine mammals, sea turtles, and fish, and other forms of disturbance. An integral part of the planned survey is a monitoring and mitigation program designed to minimize impacts of the proposed activities on marine animals present during the proposed research, and to document as much as possible the nature and extent of any effects. Injurious impacts to marine mammals and sea turtles have not been proven to occur near airgun arrays, even with higher discharge volumes than that proposed in the present study, and also are not likely to be caused by the other types of sound sources to be used. The planned monitoring and mitigation measures would minimize the possibility of such effects.

Protection measures designed to mitigate the potential environmental impacts to marine mammals and turtles will include the following: ramp ups, a minimum of one dedicated observer maintaining a visual watch during all daytime GI gun operations, 30 min of observations before and during ramp ups during the day and at night, shut downs when marine mammals or sea turtles are detected in or about to enter designated exclusion zones, power downs during turns, shut downs if North Atlantic right whales

are sighted at any distance from the source vessel (given their special status), and avoidance of concentrations of sperm, humpback, sei, blue, or fin whales. Rice and its contractors are committed to apply these measures in order to minimize effects on marine mammals and other environmental impacts.

With the planned monitoring and mitigation measures, unavoidable impacts to each species of marine mammal and turtle that could be encountered are expected to be limited to short-term, localized changes in behavior and distribution near the seismic vessel. At most, effects on marine mammals may be interpreted as falling within the U.S. Marine Mammal Protection Act (MMPA) definition of “Level B Harassment” for those species managed by NMFS. No long-term or significant effects are expected on individual marine mammals, sea turtles, or the populations to which they belong, or on their habitats.

The proposed project would have little impact on fish resources. Any effects on EFH would consist of short-term disturbance that could lead to temporary relocation of EFH species or their food. Impacts of seismic sounds on birds are possible, although none are expected to be significant to their populations. Rice will coordinate with recreational and commercial fisheries to minimize the potential for any impacts.

LIST OF ACRONYMS

~	approximately
ALWTRP	Atlantic Large Whale Take Reduction Plan
asl	above sea level
ASMFC	Atlantic States Marine Fisheries Commission
CETAP	Cetacean and Turtle Assessment Program
CITES	Convention on International Trade in Endangered Species
CPA	Closest Point of Approach
CPUE	Catch per Unit Effort
CT	Connecticut
CV	Coefficient of Variation
DMA	Dynamic Management Area
DPS	Distinct Population Segment
E	East
EA	Environmental Assessment
EEZ	Exclusive Economic Zone
EFH	Essential Fish Habitat
ESA	(U.S.) Endangered Species Act
EWS	Early Warning System
ft	feet
FL	Florida
FMC	Fishery Management Council
FMP	Fishery Management Plan
GI gun	Generator-Injector gun
GIS	Geographic Information System
h	hour
hp	horsepower
ha	hectares
HAPC	Habitat Area of Particular Concern
IHA	Incidental Harassment Authorization (under MMPA)
in	inch
IODP	Integrated Ocean Drilling Program
IUCN	International Union for the Conservation of Nature
IWC	International Whaling Commission
kHz	kilohertz
kt	knot
L-DEO	Lamont-Doherty Earth Observatory of Columbia University
m	meter
MA	Massachusetts
MAB	Mid-Atlantic Bight
MADMF	Massachusetts Division of Marine Fisheries
MAFMC	Mid-Atlantic Fishery Management Council
MCS	Multichannel Seismic
ME	Maine
mi	mile
min	minute
MMO	Marine Mammal Observer
MMPA	(U.S.) Marine Mammal Protection Act
MPA	Marine Protected Area
ms	millisecond

mt	metric tonnes
MTTS	Masked Temporary Threshold Shift
MV	the island of Martha's Vineyard
NH	New Hampshire
NJ	New Jersey
n.mi.	nautical mile
NARWC	North Atlantic Right Whale Consortium
NEAQ	New England Aquarium
NEFMC	New England Fishery Management Council
NEFSC	Northeast Fisheries Science Center
NE OPERA	(U.S.) Navy Northeast Operating Area
NEPA	(U.S.) National Environmental Policy Act
NC	North Carolina
NMFS	(U.S.) National Marine Fisheries Service
NOAA	(U.S.) National Oceanic and Atmospheric Administration
NRC	(U.S.) National Research Council
NSF	National Science Foundation
NVD	Night Vision Device
NWA	Northwest Atlantic Ocean
NY	New York
PAM	Passive Acoustic Monitoring
PBR	Potential Biological Removal
pk	peak
ppt	parts per thousand
psi	pounds per square inch
PTS	Permanent Threshold Shift
RI	Rhode Island
Rice	Rice University
RL	Received Level
rms	root-mean-square
rpm	rotations per minute
s	second
SA	Steamship Authority
SAS	Sighting Advisory System
SBP	Sub Bottom Profiler
SFA	Salmon Fishing Area
SL	Source Level
SMA	Seasonal Management Area
SPL	sound pressure level
TSS	(Boston) Traffic Separation Scheme
TTS	Temporary Threshold Shift
UNEP	United Nations Environment Program
U.S.	United States of America
USFWS	U.S. Fish and Wildlife Service
USCG	U.S. Coast Guard
vs.	versus
VTR	Vessel Trip Reports
W	West
yd	yard

I. PURPOSE AND NEED

Rice University (Rice), Department of Earth Sciences, plans to conduct a high-resolution multi-channel seismic survey (MCS) in the Northwest Atlantic Ocean (NWA). Funding to support the research is provided by the U.S. National Science Foundation (NSF). The marine seismic survey will involve the oceanographic research vessel R/V *Endeavor*, which is owned by NSF and operated by the University of Rhode Island (RI). The vessel will use a low-energy, portable seismic system to conduct the seismic survey. The survey is presently scheduled to occur during ~12–25 August 2009, and will take place entirely within the U.S. Exclusive Economic Zone (EEZ), over the continental shelf southeast of the island of Martha's Vineyard (MV), Massachusetts (MA), and likely also in Nantucket Sound.

NSF, as the funding and action agency, has a mission to "promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense…". The proposed seismic survey is part of a research proposal recommended for funding by an expert review panel. The proposed survey will provide data integral to advancing scientific understanding of the distribution and abundance of freshwater sequestered beneath the continental shelf.

The proposed survey will examine stratigraphic controls on freshwater beneath the continental shelf off the U.S. east coast. In coastal settings worldwide, large freshwater volumes are sequestered in permeable continental shelf sediments. Freshwater storage and discharge have been documented off North and South America, Europe, and Asia. The proposed survey will investigate the Atlantic continental shelf off New England, where freshwater extends up to 100 km offshore. Using high-resolution mathematical models and existing data, it is estimated that ~1300 km^3 of freshwater is sequestered in the continental shelf from New York to Maine. However, the models indicate that the amount of sequestered freshwater is highly dependent on the thickness and distribution of aquifers and aquicludes. The proposed survey will provide imaging of the subsurface and characterize the distribution of aquifers and aquicludes off MV.

The purpose of this Environmental Assessment (EA) is to provide the information needed to assess the potential environmental impacts associated with the use of two low-energy Generator-Injector (GI) guns, a Knudsen 3260 echosounder, an EdgeTech sub-bottom profiler (SBP), and "boomer" system to image sub-bottom seafloor layers during the proposed study. The EA was prepared under the National Environmental Policy Act (NEPA). The EA addresses potential impacts of the proposed seismic survey on marine mammals, as well as other species of concern near the study area, including sea turtles, seabirds, fish, and invertebrates. The EA will also provide useful information in support of the application for an Incidental Harassment Authorization (IHA) from the National Marine Fisheries Service (NMFS). The requested IHA would, if issued, allow the non-intentional, non-injurious "take by harassment" of small numbers of marine mammals during the proposed seismic survey by Rice in the NWA during August 2009.

To be eligible for an IHA, the proposed "taking" (with mitigation measures in place) must not cause serious physical injury or death of marine mammals, must have negligible impacts on the species and stocks, must "take" no more than small numbers of those species or stocks, and must not have an immitigable adverse impact on the availability of the species or stocks for legitimate subsistence uses.

Numerous species of cetaceans and pinnipeds inhabit the NWA. Several of these species are listed as ***endangered*** under the U.S. Endangered Species Act (ESA), including North Atlantic right, humpback, sei, fin, blue, and sperm whales. Other species of concern that could occur in the study area are the ***endangered*** leatherback and Kemp's ridley turtles, the ***threatened*** loggerhead and green turtles, and the

endangered roseate tern. The ***endangered*** Atlantic salmon and shortnose sturgeon may occur at low densities in or near the area at the time of the survey.

Protection measures designed to mitigate the potential environmental impacts are also described in this EA as an integral part of the planned activities. With these mitigation measures in place, any impacts on marine mammals and sea turtles are expected to be limited to short-term, localized changes in behavior of small numbers of animals. No long-term or significant effects are expected on individual mammals, turtles, or populations. The proposed project would also have little impact on fish resources. There are no potential effects on Essential Fish Habitat (EFH) or Habitat Areas of Particular Concern (HAPC). Impacts of seismic sounds on birds are possible, although none are expected to be significant to individual birds or their populations.

II. ALTERNATIVES INCLUDING PROPOSED ACTION

Three alternatives are evaluated: (1) the proposed seismic survey and issuance of an associated IHA, (2) a corresponding seismic survey at an alternative time, along with issuance of an associated IHA, and (3) no action alternative.

Proposed Action

The project objectives and context, activities, and mitigation measures for Rice's planned seismic survey are described in the following subsections.

(1) Project Objectives and Context

Rice plans to conduct the low-energy seismic survey off MV in the NWA. The survey will examine the distribution and amounts of freshwater sequestered within the continental shelf off the U.S. northeast coast. The program will provide data integral to improved models to estimate the abundance of sequestered freshwater and will provide site survey data for an Integrated Ocean Drilling Program (IODP) proposal to drill these freshwater resources for hydrogeochemical, biological, and climate studies.

Combined seismic and drilling data could help identify undeveloped freshwater resources that may represent a resource to urban coastal centers, if accurately characterized and managed. On a global scale, vast quantities of freshwater have been sequestered in the continental shelf and may represent an increasingly valuable resource to humans. This survey will help constrain process-based mathematical models for more precise estimations of the abundance and distribution of freshwater wells on the continental shelf.

(2) Proposed Activities

(a) Location of the Activities

The proposed survey will encompass the area 39.8–41.5°N, 69.8–70.6°W (Fig. 1). Water depths in the study area range from ~20 to ~125 m, but are typically <100 m. The survey will take place in Nantucket Sound and south of Nantucket and MV. The ship will approach the south shore of MV within 10 km. The seismic survey will be conducted in the territorial waters and EEZ of the U.S. and is scheduled to occur during 12–25 August 2009. Some minor deviation from these dates is possible, depending on logistics and weather.

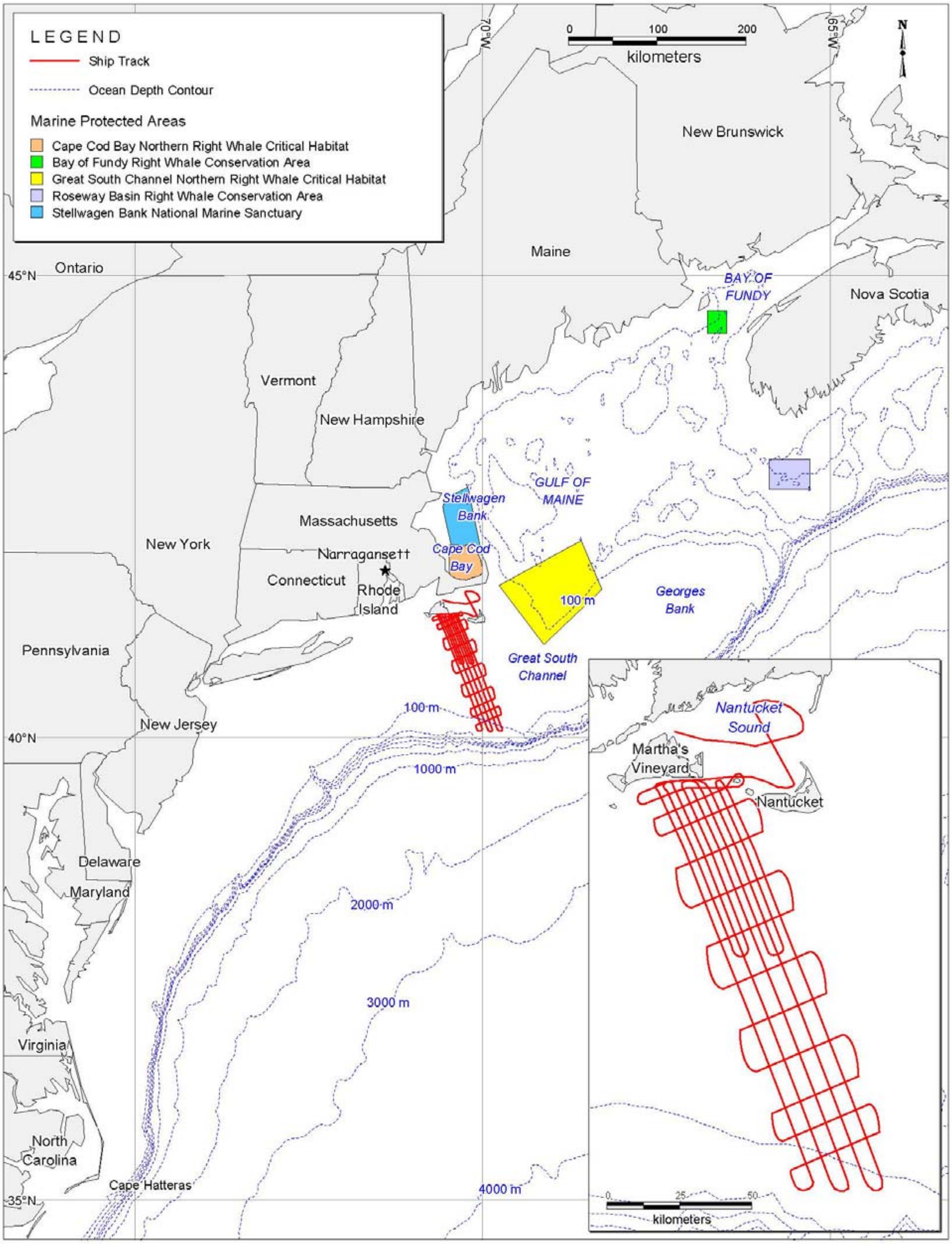

FIGURE 1. Study area and proposed seismic transect lines for the survey in the Northwest Atlantic Ocean, August 2009. For illustrative purposes, U.S. federal and Canadian protected areas are also shown (see § III, *Protected Areas*).; the survey will not occur in those protected areas.

(b) Description of the Activities

The survey will involve one source vessel, the R/V *Endeavor*. The *Endeavor* will deploy two GI guns as an energy source, although only a single GI gun or 15 in^3 watergun may be used in shallow water areas of the survey. The receiving system for the returning acoustic signals will consist of one 600-m, digital, high-resolution streamer towed at a depth of ~3 m. As the GI guns (or watergun) are towed along the survey lines, the hydrophone streamer will receive the returning acoustic signals and transfer the data to the on-board processing system.

The planned seismic survey will consist of ~1757 km of survey lines and turns (Fig. 1). All survey effort will occur within 200 km of MV. Most of the survey effort (~1638 km) will take place in water <100 m deep, and ~119 km will occur just past the shelf edge, in water depths >100 m.

In addition to the operations of the GI guns, a Knudsen 3260 echosounder, an EdgeTech SBP, and/or an Applied Acoustics 'boomer' system will be operated from the *Endeavor* during the survey for additional sub-surface imaging. All planned geophysical data acquisition activities will be conducted by the scientific team who proposed the study; the scientific team is headed by Dr. B. Dugan of Rice University, Dr. D. Lizarralde of Woods Hole Oceanographic Institution, and Dr. M. Person of New Mexico Institute of Mining and Technology. The vessel will be self-contained, and the crew will live aboard the vessel for the entire cruise.

(c) Schedule

The *Endeavor* is expected to depart Narragansett, RI, on ~12 August 2009 for a ~4-hr transit to the study area southeast of MV (Fig. 1). Seismic operations will commence upon arrival at the study area, with highest priority given to the central NNW-SSE line, followed by the WSW-ENE lines, each of which cross the proposed IODP sites; lowest priority will be given to the survey lines in Nantucket Sound. The 14-day program will consist of ~11 days of seismic operations, and three contingency days in case of inclement weather. The *Endeavor* will return to Narragansett on ~25 August 2009. The exact dates of the activities depend on logistics, weather conditions, and the need to repeat some lines if data quality is substandard.

(d) Source Vessel Specifications

The *Endeavor* will be used as the source vessel. The *Endeavor* will tow the two GI guns and one 600-m streamer containing hydrophones along predetermined lines (Fig. 1). Given the presence of the streamer and GI guns behind the vessel, the turning rate and maneuverability of the vessel is slightly limited.

The *Endeavor* has a length of 56.4 m, a beam of 10.1 m, and a maximum draft of 5.6 m. The *Endeavor* has been operated by the University of Rhode Island's Graduate School of Oceanography for over thirty years to conduct oceanographic research throughout U.S. and world marine waters. The ship is powered by one GM/EMD diesel engine, producing 3050 hp, which drives the single propeller directly at a maximum of 900 revolutions per minute (rpm). The vessel also has a 320-hp bowthruster, which is not used during seismic acquisition. The optimal operation speed during seismic acquisition will be ~7.4 km/h. When not towing seismic survey gear, the *Endeavor* can cruise at 18.5 km/h. The *Endeavor* has a range of 14,816 km.

The *Endeavor* will also serve as the platform from which vessel-based marine mammal (and sea turtle) observers (MMOs) will watch for animals before and during GI gun operations, as described in § II(3), below.

Other details of the *Endeavor* include the following:

Owner:	National Science Foundation
Operator:	University of Rhode Island
Flag:	United States of America
Date Built:	1976 (Refit in 1993)
Gross Tonnage:	298
Accommodation Capacity:	30 including ~17 scientists

(e) GI Gun Description

During the survey, two GI guns and a 600-m hydrophone streamer will be towed behind the *Endeavor*. The GI guns will be towed at a depth of ~3 m. The generator chamber of each GI gun is responsible for generating the sound pulse and has a volume of 45 in^3. The injector chamber (also 45 in^3) injects air into the previously-generated bubble to maintain its shape, but does not introduce appreciably more sound into the water. The GI guns are relatively small compared to most other airgun arrays used for seismic surveys. Seismic pulses will be emitted at intervals of five seconds. Both GI guns will be fired simultaneously, for a total discharge volume of 90 in^3. The operating pressure will be 2000 psi. The GI guns will be towed on a single line from the *Endeavor*'s stern on the port side; the first will be located 25 m behind the *Endeavor*, and the second will be positioned 2.4 m behind the first GI gun. It is possible that no GI- or waterguns will operate during the Nantucket Sound survey lines, but rather the echosounder, SBP, and/or boomer will be used. Estimates of trackline effort and modeling of sound radii in the following sections were made based on continuous operation of the two GI guns during survey lines and one GI gun during turns.

Because the actual source consists of two GI guns 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 GI guns.

A single GI gun, a single 15 in^3 watergun, or a boomer system (see description below, under "Description of Operations") may be used in shallow waters with sandy seafloors if the two GI guns do not provide accurate seafloor imaging. The watergun is a marine seismic sound source that uses an implosive mechanism to provide an acoustic signal. Waterguns provide a richer source spectra in high frequencies (>200 Hz) than those of GI or airguns. The 15-in^3 watergun potentially provides a cleaner signal for high-resolution studies in shallow water, with a short pulse (<30 ms) providing resolution of ~10 m. The operating pressure will be 2000 psi. Peak pressure of the single watergun and the boomer system is estimated to be ~212 dB (0.4 bar-m). Thus, both sources would have a considerably lower source level than the two GI guns or the single GI gun.

GI Airgun Specifications

Energy Source:	One or two GI guns of 45 in^3
Source output, 2 guns (downward):	0-pk is 3.4 bar-m (230.7 dB re 1 µPa·m$_{p}$); pk-pk is 6.2 bar-m (235.9 dB re 1 µPa·m$_{p-p}$)
Source output, 1 gun (downward):	0–pk is 1.8 bar-m (225.3 dB re 1 µPa·m$_{p}$); pk–pk is 3.4 bar-m (230.7 dB re 1 µPa·m$_{p-p}$)
Towing depth of energy source:	3 m
Air discharge volume:	~45 or 90 in^3
Dominant frequency components:	2–188 Hz
Gun positions used:	One GI gun or two GI guns in line, 2.4 m apart
Gun volumes at each position (in^3):	45, 45

(f) Dual-frequency Echosounder, SBP, and 'Boomer' system

Along with the GI-gun operations, up to three additional standard acoustical data acquisition systems will be operated during most of the cruise. The ocean floor will be mapped with the 3.5–12-kHz Knudsen 3260 dual-frequency echosounder, and either a 0.5–12 kHz EdgeTech SBP or 0.3-3 kHz 'boomer' system will also be operated for sub-bottom seafloor imaging. The echosounder will be operated simultaneously with the GI guns and boomer system, but not with the SBP. The SBP will be used simultaneously with the GI guns in deeper water (>30–40 m), whereas the 'boomer' system will be used simultaneously with the GI guns in shallower water (<30–40 m).

The Knudsen 3260 is a deep-water, dual-frequency echosounder with operating frequencies of 3.5 and 12 kHz. The high frequency (12 kHz) can be used to record water depth or to track pingers attached to various instruments deployed over the side. The low frequency (3.5 kHz) is used for sub-bottom profiling. Both frequencies will be used simultaneously during the present study. It will be used with a hull-mounted, downward-facing transducer. A pulse up to 24 ms in length is emitted every several seconds with a nominal beam width of 80º. Maximum output power at 3.5 kHz is 10 kW and at 12 kHz it is 2 kW. The maximum source output (downward) for the 3260 is estimated to be 211 dB re 1 μPa·m at 10 kW.

The SBP is normally operated to provide information about sedimentary features and bottom topography; it will provide a 10-cm resolution of the sub-floor. During operations in deeper waters (>30–40 m), an EdgeTech 3200-XS SBP will be operated from the ship with a SB-512i towfish that will be towed at a depth of 5 m. It will transmit and record a 0.5-12-kHz swept pulse (or chirp), with a nominal beam width of 16–32º. The SBP will produce a 30-ms pulse repeated at 0.5- to 1-s intervals. Depending on seafloor conditions, it could penetrate up to 100 m.

The 'boomer' system will be an alternative source of sub-floor imaging in shallower waters (<30–40 m). An Applied Acoustics AA200 'boomer' system run by the National Oceanography Centre will operate from ~0.3 to 3 kHz. The system will be surface-towed, and a 60-m hydrophone streamer will receive its pulses. The streamer will be towed at 1 m depth and ~25–30 m behind the *Endeavor*. A 0.1-ms pulse will be transmitted at 1-s intervals. The normal source output (downward) is 212 dB re 1 μPa·m.

(3) Monitoring and Mitigation Measures

Numerous species of marine mammals are known to occur in the proposed study area. However, the number of individual animals expected to be approached closely during the proposed activities will be small in relation to regional population sizes. With the proposed monitoring and mitigation provisions, effects on those individuals are expected to be limited to minor behavioral disturbance. Those effects are expected to have negligible impacts both on individual marine mammals and on the associated species and stocks.

To minimize the likelihood that impacts will occur to the species and stocks, GI gun operations will be conducted in accordance with all applicable U.S. federal regulations and IHA requirements. Rice will coordinate all IHA activities with the relevant U.S. federal agencies, particularly NMFS. The proposed activities will take place in the territorial waters and EEZ of the U.S.A.

The following subsections provide more detailed information about the monitoring and mitigation measures that are an integral part of the planned activities. The procedures described here are based on protocols used during previous seismic research cruises as approved by NMFS, and on best practices recommended in Richardson et al. (1995), Pierson et al. (1998), and Weir and Dolman (2007).

(a) Visual Monitoring

MMOs will watch for marine mammals and turtles near the seismic source vessel during all daytime GI-gun operations and during any start ups of the GI guns at night. GI-gun operations will be suspended when marine mammals or turtles are observed within, or about to enter, designated exclusion zones [see subsection (c) below] where there is concern about effects on hearing or other physical effects. MMOs will also watch for marine mammals and turtles near the seismic vessel for at least 30 min prior to the planned start of GI-gun operations after an extended shut down of the GI guns. When feasible, observations will also be made during daytime periods when the *Endeavor* is underway without seismic operations, such as during transits.

During seismic operations in the NWA, three visual observers will be based aboard the *Endeavor*. MMOs will be appointed by Rice with NMFS concurrence. At least one MMO, and when practical two MMOs, will monitor for marine mammals and turtles near the seismic vessel during ongoing daytime operations and nighttime start ups of the GI guns. Use of two simultaneous observers will increase the proportion of the animals present near the source vessel that are detected. MMO(s) will be on duty in shifts of duration no longer than 4 h. Other crew will also be instructed to assist in detecting marine mammals and turtles and implementing mitigation requirements (if practical). Before the start of the seismic survey the crew will be given additional instruction regarding how to do so.

The *Endeavor* is a suitable platform for marine mammal and turtle observations. Observations may take place from the flying bridge ~11 m above sea level (asl) or the bridge (8.2 m asl). During daytime, the MMO(s) will scan the area around the vessel systematically with reticle binoculars (e.g., 7×50 Fujinon) and with the naked eye. During darkness, night vision devices (NVDs) will be available (ITT F500 Series Generation 3 binocular-image intensifier or equivalent), when required.

When mammals or turtles are detected within or about to enter the designated exclusion zone, the GI guns will be shut down immediately. The MMO(s) will continue to maintain watch to determine when the animal(s) are outside the exclusion zone. Airgun operations will not resume until the animal has left the exclusion zone.

The vessel-based monitoring will provide data 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. It will also provide the information needed in order to shut down the GI guns at times when mammals or turtles are present in or near the exclusion zone. When a sighting is made, the following information about the sighting will be recorded:

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

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

All observations and shut downs will be recorded in a standardized format. Data will be entered into a custom electronic database. 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

1. The basis for real-time mitigation (GI gun shut down).
2. Information needed to estimate the number of marine mammals potentially taken by harassment, which must be reported to NMFS.
3. Data on the occurrence, distribution, and activities of marine mammals and turtles in the area where the seismic study is conducted.
4. Information to compare the distance and distribution of marine mammals and turtles relative to the source vessel at times with and without seismic activity.
5. Data on the behavior and movement patterns of marine mammals and turtles seen at times with and without seismic activity.

(b) Reporting

A 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 be submitted to NMFS, providing full documentation of methods, results, and interpretation pertaining to all monitoring. 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 any potential "take" of marine mammals by harassment or in other ways.

(c) Proposed Exclusion Zones

Acoustic Measurement Units.—The sound pressure field of two 45-in^3 GI guns has not been modeled, but those for two 45-in^3 Nucleus G guns and one 45-in^3 GI gun have been modeled by Lamont-Doherty Earth Observatory of Columbia University (L-DEO) in relation to distance and direction from the guns (Figs. 2 and 3). The GI gun is essentially two G guns that are joined head to head. The G-gun signal has more energy than the GI-gun signal, but the peak energy levels are equivalent and appropriate for modeling purposes. The L-DEO model does not allow for bottom interactions, and is most directly applicable to deep water. Based on the modeling, estimates of the maximum distances from the GI guns where sound levels of 190, 180, 170, and 160 dB re 1 μPa_{rms} are predicted to be received in deep (>1000-m) water are shown in Table 1. Because the model results are for G guns, which have more energy than GI guns of the same size, those distances are overestimates of the distances for the 45-in^3 GI guns.

Empirical data concerning the 180-, 170-, and 160-dB distances for various airgun configurations, including a pair of GI guns, have been acquired based on measurements during an acoustic verification study conducted by L-DEO in the northern Gulf of Mexico (Tolstoy et al. 2004a,b). Although the results are limited, the data showed that radii around the GI guns where the received level would be 180 dB re 1 μPa_{rms}, the safety criterion applicable to cetaceans (NMFS 2000), vary with water depth. Similar depth-related variation is likely in the 190-dB distances applicable to pinnipeds. Based on the empirical data, correction factors were developed for water depths 100–1000 m and <100 m.

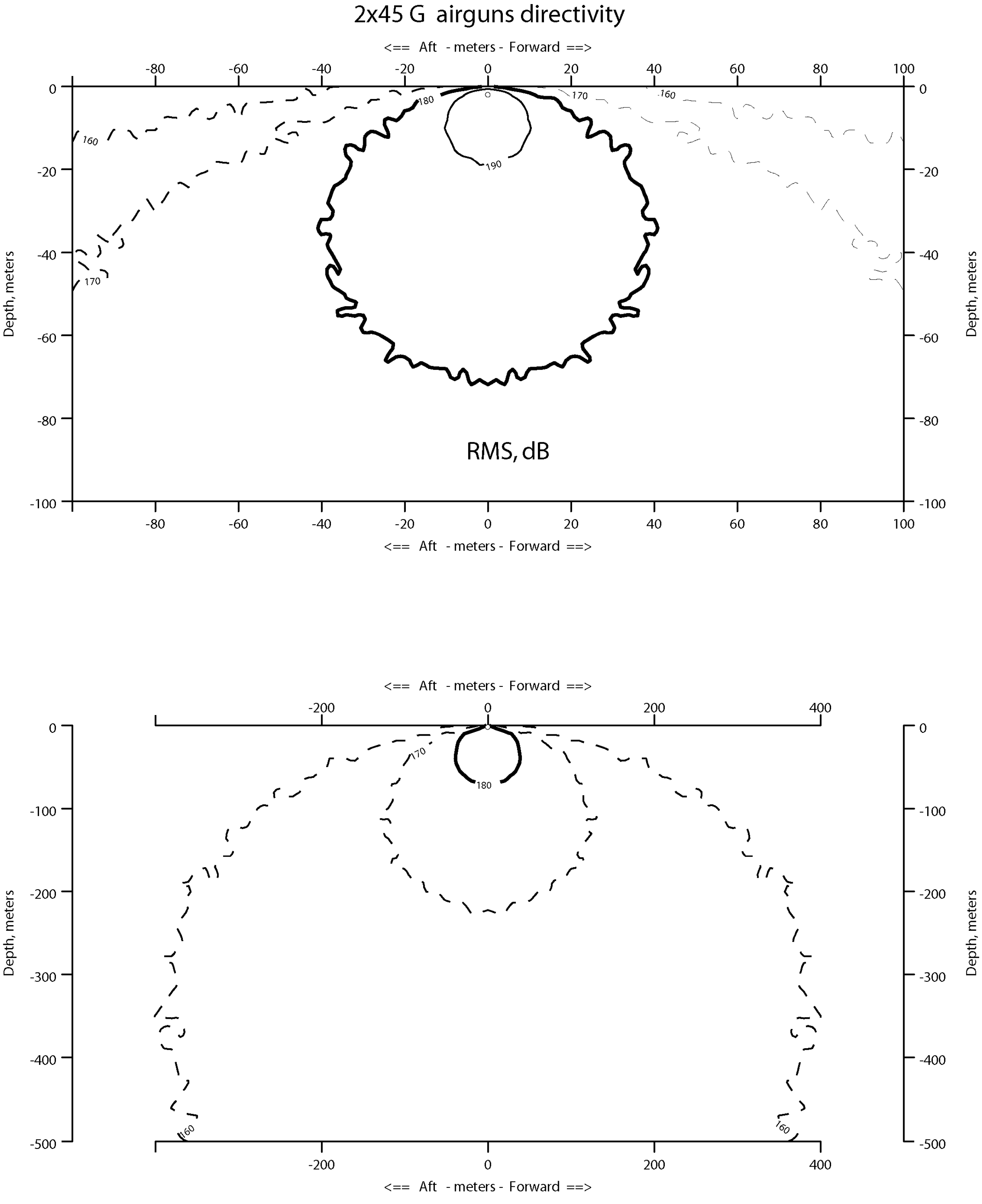

FIGURE 2. Modeled received sound levels from two 45-in^3 G guns, similar to the two 45-in^3 GI guns that will be used during the NWA survey. Model results provided by L-DEO.

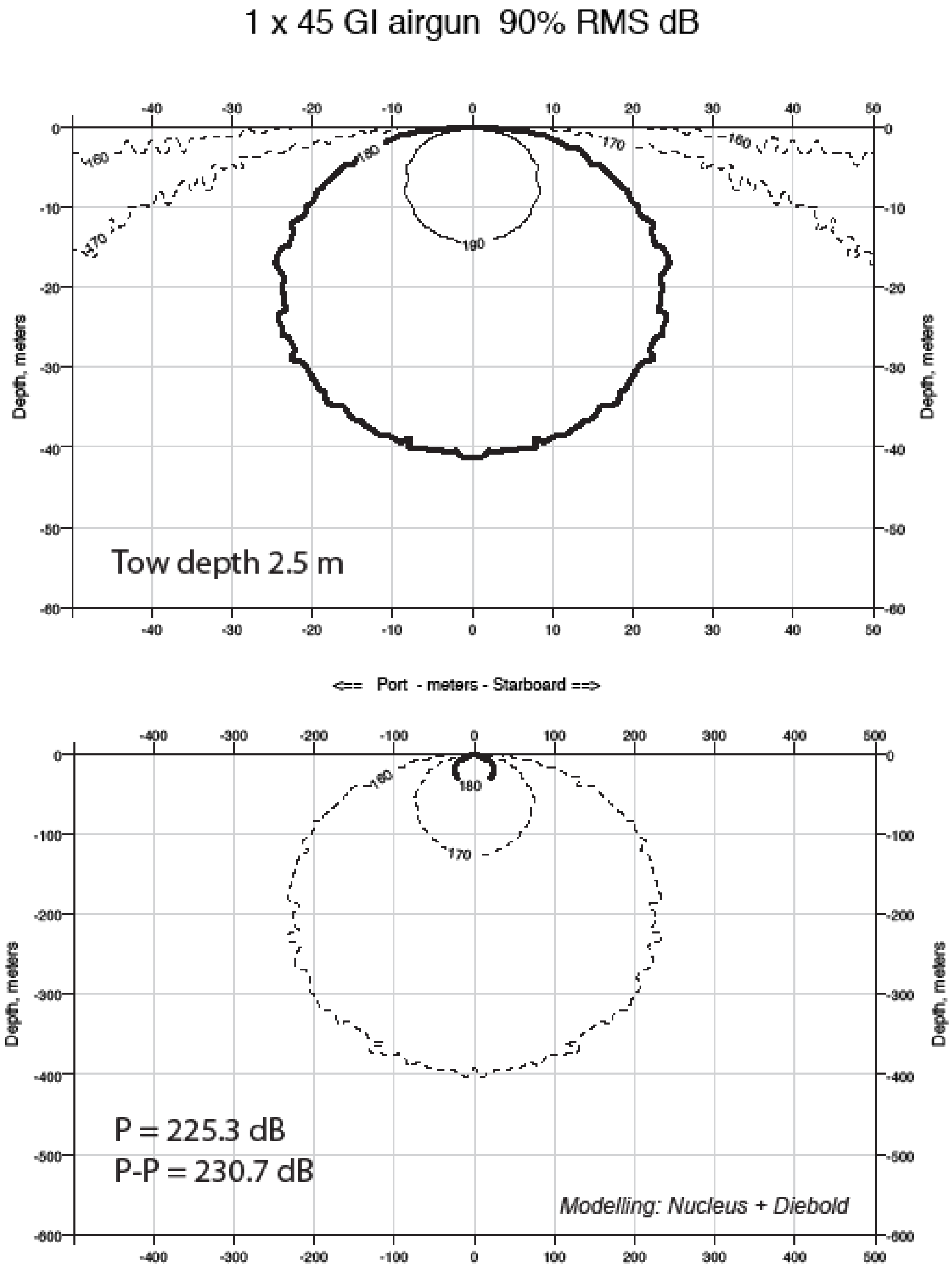

FIGURE 3. Modeled received sound levels from the 45-in^3 GI gun that will be used on turns during the NWA survey. Model results provided by L-DEO.

TABLE 1. Distances to which sound levels ≥190, 180, 170, and 160 dB re 1 µPa (rms) might be received from two 45-in^3 G guns, similar to the two 45-in^3 GI guns that will be used during the proposed seismic survey, and one 45-in^3 GI gun that will be used during turns. Distances are based on model results provided by L-DEO.

		Estimated Distances at Received Levels (m)			
Source	Water depth	190 dB	180 dB	170 dB	160 dB
Two 45-in^3 G guns	100–1000 m	15	60	188	525
	<100 m	147	296	536	1029
One 45-in^3 GI gun	100–1000 m	12	35	105	330
	<100 m	95	150	230	570

- The empirical data indicate that, for ***deep water*** (>1000 m), the L-DEO model tends to overestimate the received sound levels at a given distance (Tolstoy et al. 2004a,b). However, to be precautionary pending acquisition of additional empirical data, it is proposed that safety radii in deep water will be the values predicted by L-DEO's model (Table 1). However, operations will not occur in water depths >1000 m during the present study.
- Empirical measurements of sounds from the GI guns were not conducted for ***intermediate depths*** (100–1000 m). On the expectation that results would be intermediate between those from shallow and deep water, a correction factor of 1.5× is applied to the estimates provided by the model for deep-water situations to obtain estimates for intermediate-depth sites.
- Empirical measurements indicated that in ***shallow water*** (<100 m), the L-DEO model ***underestimates*** actual levels. In L-DEO projects, the exclusion zones are typically based on measured values and range from 1.3 to 15× higher than the modeled values depending on the size of the airgun array and the sound level measured (Tolstoy et al. 2004a,b). During the proposed cruise, similar factors are applied to derive appropriate shallow-water radii from the modeled deep-water radii (Table 1).

Using the modeled distances and various correction factors, Table 1 shows the distances at which four rms sound levels are expected to be received from the two GI guns and the single GI gun in two different water depths. The 180 and 190 dB re 1 μPa_{rms} distances are the safety criteria as specified by NMFS (2000) and are applicable to cetaceans and pinnipeds, respectively. The 180-dB distance will also be used as the exclusion zone for sea turtles, as required by NMFS in most other recent seismic projects (e.g., Smultea et al. 2004; Holst et al. 2005). If marine mammals or turtles are detected within or about to enter the appropriate exclusion zone for two GI guns, the GI guns or single GI gun, watergun, or boomer will be shut down immediately.

Detailed recommendations for new science-based noise exposure criteria were published recently (Southall et al. 2007). Rice will be prepared to revise its procedures for estimating numbers of mammals "taken", exclusion zones, etc., as may be required by any new guidelines that result. As yet, NMFS has not specified a new procedure for determining exclusion zones.

(d) Mitigation During Operations

Mitigation measures that will be adopted during the proposed survey include (1) shut-down procedures, (2) ramp-up procedures, (3) power-down during turns, and (4) special procedures for situations or species of particular concern (see "Special procedures for situations and species of particular concern", below).

Shut-down procedures

If a marine mammal or turtle is detected outside the exclusion zone but is likely to enter the exclusion zone, the seismic source will be shut down before the animal is within the exclusion zone. Likewise, if a mammal or turtle is already within the safety zone when first detected, the seismic source will be shut down immediately.

Following a shut down, seismic activity will not resume until the marine mammal or turtle has cleared the exclusion zone. The animal will be considered to have cleared the exclusion zone if it

- is visually observed to have left the exclusion zone, or
- has not been seen within the zone for 10 min in the case of small odontocetes and pinnipeds, or
- has not been seen within the zone for 15 min in the case of mysticetes and large odontocetes, including sperm, pygmy sperm, dwarf sperm, and beaked whales, or
- the vessel has moved outside the exclusion zone for turtles (up to 5 min) depending on sighting distance, depth, and vessel speed [based on the lengths of time it would take the vessel to leave the turtle behind and outside of the exclusion zone].

Ramp-up procedures

A ramp-up procedure will be followed when the GI guns begin operating after a specified period without GI gun operations. It is proposed that, for the present cruise, this period would be ~1–2 min. This period is based on the 180-dB radii for the GI guns (see Table 1) in relation to the planned speed of the *Endeavor* while shooting (see above).

Ramp up will begin with a single GI gun (45 in^3). The second GI gun (45 in^3) will be added after 5 min. During ramp up, the MMOs will monitor the exclusion zone, and if marine mammals or turtles are sighted, a shut down will be implemented as though both GI guns were operational.

If the complete exclusion zone has not been visible for at least 30 min prior to the start of operations in either daylight or nighttime, ramp up will not commence. If one GI gun has operated, ramp up to full power will be permissible at night or in poor visibility, on the assumption that marine mammals and turtles will be alerted to the approaching seismic vessel by the sounds from the single GI gun and could move away if they choose. A ramp up from a shut down may occur at night, but only in intermediate-water depths, where the safety radius is small enough to be visible. Ramp up of the GI guns will not be initiated if a sea turtle or marine mammal is sighted within or near the applicable exclusion zones during the day or close to the vessel at night.

Power-down during turns

A power-down involves decreasing the number of GI guns in use from two to one. During turns between successive survey lines, a single GI gun will be operated. The continued operation of one gun is intended to alert marine mammals to the presence of the survey vessel in the area.

Special procedures for situations and species of particular concern

Several species of particular concern could occur in the study area. Special mitigation procedures will be used for those species, as follows:

- The GI guns will be shut down if a North Atlantic right whale is sighted at any distance from the vessel because of its rarity and conservation status
- Concentrations of humpback, fin, sperm, blue, and sei whales will be avoided.

Alternative Action: Another Time

An alternative to issuing the IHA for the period requested and to conducting the project then, is to issue the IHA for another time and to conduct the project at that alternative time. The proposed time for the NWA cruise (~12–25 August 2009) is the most suitable time logistically for the *Endeavor* and the participating scientists. If the IHA is issued for another period, it could result in significant delay and disruption not only of the proposed cruise, but of additional geophysical studies that are planned by other universities and researchers for 2009 and beyond. An evaluation of the effects of this alternative action is given in § IV.

No Action Alternative

An alternative to conducting the proposed activities is the "No Action" alternative, i.e., do not issue an IHA and do not conduct the research operations. If the research is not conducted, the "No Action" alternative would result in no disturbance to marine mammals due to the proposed activities.

The seismic data from the proposed survey will be used to determine the distribution and abundance of freshwater sequestered in the continental shelf within the area. Important aspects of the project are that (1) new, undeveloped freshwater resources will be surveyed in a region with several large urban centers that have extensive freshwater needs; (2) information obtained from this survey will affect a broad range of proposed and on-going hydrogeochemical, biological, and climate studies in the region; and (3) ultimately the study of the properties of freshwater sequestered in the continental shelf will help constrain models used to estimate the quantities of these resources in North America and perhaps globally. Under the "No Action" alternative, this valuable scientific information would not become available.

In addition to forcing cancellation of the planned seismic survey in the NWA, the "No Action" alternative could also, in some circumstances, result in significant delay of other geophysical studies that are planned by other oceanographic institutions for 2009 and beyond, depending on the timing of the decision. The entire proposal, based on the premise of collecting these data, would be compromised. Cancellation (no action) for this cruise would lessen available data and support for the academic institutions involved. Data collection is an essential first step for a much greater effort to analyze and report information for the significant topics indicated. The ~11 days of seismic effort provides material for years of analyses involving multiple professors, students, and technicians. The lost opportunity to collect valuable scientific information is compounded by lost opportunities for support of research infrastructure, training, and professional career growth.

III. AFFECTED ENVIRONMENT

Physical Environment and Oceanography

As a result of processes such as glaciation, volcanism, erosion, and sea level rise, the bathymetry off the U.S. east coast varies considerably from the Gulf of Maine to Cape Hatteras, NC. The continental shelf extends over much of the Gulf of Maine and northeastern U.S. waters, continues south as the mid-Atlantic Bight (MAB), and the continental shelf tapers very narrowly off of Cape Hatteras (see Fig. 1). From Florida to Cape Cod, the continental shelf has a very gradual slope with a relatively uniform seafloor and is relatively shallow. Northeast of Cape Cod and into the Gulf of Maine, the continental shelf is marked with considerable seafloor relief attributable to glaciation. Georges Bank forms a massive shoal to the northeast of the proposed study area and is flanked to the west and northeast by two channels, the Northeast and Great South Channels. Shallow waters, strong currents, and tidal forces contribute to year-round well-mixed and productive waters over Georges Bank (Bumpus 1976 *in* DoN 2005). The continental shelf break, where it transitions into slope waters, features an abrupt change to a steep gradient. Several canyons and seamounts characterize the slope and offshore waters of the NWA, and both types of oceanographic features tend to contain higher biological productivity than surrounding slope and deep waters.

Three water masses determine the physical environment off the U.S. east coast: coastal or shelf waters, slope waters, and the Gulf Stream (summarized in DoN 2005). Coastal waters from the North Atlantic, mostly originating in the Labrador Sea, move southwesterly over the continental shelf until reaching Cape Hatteras, where they are entrained between slope waters and the Gulf Stream. The continental slope waters of the western North Atlantic are marked by mixing of colder shelf waters and the warm Gulf Stream; continental slope waters are strongly influenced by wind, tides, and variability in the Gulf Stream. North of Cape Hatteras, an elongated cyclonic gyre of slope water forms because of the southwest flow of shelf water and the northward-flowing Gulf Stream; it is present during most of the year and shifts seasonally relative to the position of the Gulf Stream. The Gulf Stream flows through the Straits of Florida and northward parallel to the continental shelf; it is a powerful surface current carrying warm water into the cooler North Atlantic. It veers to the west several hundred kilometers south of the proposed study area. Currents on and around Georges Bank move clockwise and generally southwesterly as part of the coastal current system from the North Atlantic; productive frontal boundaries often form on the edges of the bank or near the slope. The Gulf of Maine and Bay of Fundy exhibit extreme semidiurnal tidal changes; tidal currents rotate clockwise in the Gulf of Maine with well-mixed, cold waters, promoting a region of high productivity.

Sea surface temperatures vary seasonally, sometimes with more than a 20ºC temperature flux throughout the year along the coast (summarized in DoN 2005). The water column of shelf waters tends to stratify during the summer, and surface salinities generally increase as water depth increases. However, nearshore salinities are usually lower than salinities farther offshore because of terrestrial freshwater inputs. Phytoplankton abundance in shelf waters also varies seasonally: low light levels and strong mixing in winter limit primary productivity, but the mixed layer becomes shallower and light levels increase to promote phytoplankton blooms from early until late spring, when stratification of the water column limits nutrients in the sun-rich top layers. Copepods dominate the zooplankton community of New England shelf waters, and abundances are highest on the outer shelf in spring and on the inner shelf during the summer (Weibe et al. 2002).

Nantucket Sound is a broad passage separating the southern coast of Cape Cod, from northern portions of the islands of MV and Nantucket. Its maximum depth is ~20 m, and it is ~37 km long from east to west and up to ~35 km wide from north to south (MMS 2009). Nantucket Sound has several shoals, and complex currents develop because of strong, reversing, semidiurnal tidal flows. There is little vertical temperature stratification as Nantucket Sound is relatively shallow and well-mixed, although there is some intrusion of warmer continental shelf water from the east during summer (MMS 2009). Just offshore from Nantucket Sound is the confluence of cold continental shelf currents and warmer slope waters influenced by the Gulf Stream. Nantucket Sound also features a range of habitats from open water to salt marshes, estuaries, and sandy beaches.

Protected Areas

Several federal Marine Protected Areas (MPAs) or sanctuaries have been established near the proposed study area, primarily with the intention of preserving cetacean habitat (Table 2; Hoyt 2005; CetaceanHabitat 2009; see also Fig. 1). Cape Cod Bay is designated as Right Whale Critical Habitat, as

TABLE 2. Proposed and existing protected marine areas located near the proposed study area in the NWA (adapted from Hoyt 2005 and CetaceanHabitat 2009).

Protected Area	Location/Size	Cetacean Species	Notes
Cape Cod Bay/Cape Cod/Cape & Islands Ocean Sanctuary	1596 km^2; of coastline along Cape Cod, including nearshore of Martha's Vineyard and Nantucket Island	North Atlantic right whales, humpback whales, Atlantic white-sided dolphins, others	Established in 1971; managed by MA Office of Coastal Zone Management; limits marine discharges, dumping, non-renewable resource development, and other activities that disturb benthic habitat, other than fishing.
Cape Cod Bay Northern Right Whale Critical Habitat Area	1666 km^2; north and east Cape Cod Bay in the Gulf of Maine	North Atlantic right whales, humpback whales, Atlantic white-sided dolphins, others	Established in 1994 as Critical Habitat for right whales; managed by NMFS
Great South Channel Northern Right Whale Critical Habitat Area	8371 km^2; east of Cape Cod on Great South Channel	North Atlantic right whales, humpback whales, Atlantic white-sided dolphins, others	Established in 1994 as Critical Habitat for right whales; managed by NMFS
Gerry E Studds Stellwagen Bank National Marine Sanctuary	2181 km^2; east of MA on Stellwagen Bank in the Gulf of Maine	Humpback, fin, minke, North Atlantic right, and pilot whales, white-sided dolphins, harbor porpoise, others	Designated in 1992 as part of the National Marine Sanctuary Program
Jeffrey's Ledge (*proposed*)	Proposed extension to existing Stellwagen Bank National Marine Sanctuary	Humpback, fin, minke, North Atlantic right, and pilot whales, white-sided dolphins, harbor porpoise, others	Proposed to cover additional whale habitat or form new national marine sanctuary
Bay of Fundy Right Whale Conservation Area	Grand Manan Basin in the Bay of Fundy, New Brunswick, Canada	North Atlantic right, fin, and humpback whales, white-sided dolphins, harbor porpoise, others	Nursery and mating areas for North Atlantic right whales; in 2003, right whales were given right of way to shipping traffic by the Canadian government.
Roseway Basin Right Whale Conservation Area	Between Browns and Baccaro Banks off southwest Nova Scotia, Canada	North Atlantic right, sperm, fin, and humpback whales, white-sided dolphins, harbor porpoise, others	Nursery and mating areas for North Atlantic right whales; in 2003, right whales were given right of way to shipping traffic by the Canadian government.
The Gully Marine Protected Area	2364 km^2; submarine canyon on Scotian Shelf, 40 km southeast of Sable Island in the open North Atlantic	Northern bottlenose whales, occasionally minke, blue, fin, humpback, and pilot whales, dolphins, harbor porpoise	Critical habitat for a population of bottlenose whales; Designated as MPA in 2004 by Canada's Oceans Act.

is the Great South Channel Northern Right Whale Critical Habitat Area located to the east of Cape Cod. The Gerry E Studds Stellwagen Bank National Marine Sanctuary is located north of the proposed study area in the Gulf of Maine. The proposed survey is not located within any federal MPAs or sanctuaries. However, a sanctuary designated by the state of MA occurs within the study area — the Cape & Islands Ocean Sanctuary. This sanctuary includes nearshore waters of southern Cape Cod, MV, and Nantucket (see Table 2). In addition, there are four National Wildlife Refuges within the study area (Monomoy, Nantucket, Mashpee, and Nomans Island) and a National Estuarine Research Reserve (Waquoit Bay). Except for Nomans Island, these refuges and reserves are located in Nantucket Sound. Three Canadian protected areas also occur in the NWA for cetacean habitat protection, including the Bay of Fundy and Roseway Basin Right Whale Conservation Areas (Fig. 1), as well as the Gully Marine Protected Area off the Scotian Shelf.

There are several areas that are closed to commercial fishing on a seasonal basis to reduce the risk of entanglement or incidental mortality to marine mammals. To protect large whales like right, humpback, and fin whales, NMFS implemented seasonal area management zones for lobster, several groundfish, and other marine invertebrate trap/pot fisheries, prohibiting gear in the Great South Channel Critical Habitat Area from April through June; additional dynamic area management zones could be imposed for 15-day time periods if credible fisheries observers identify concentrations of right whales in areas north of 40ºN (NMFS 1999, 2008a). To reduce fishery impacts on harbor porpoises, additional time and area closures in the Gulf of Maine include fall and winter along the mid-coastal area, winter and spring in Massachusetts Bay and southern Cape Cod, winter and spring in offshore areas, and February around Cashes Ledge (NMFS 1998a). Fishermen are also required to use pingers, and New Jersey and mid-Atlantic waters could close seasonally for fishermen failing to apply specific gear modifications (NMFS 1998a).

Marine Mammals

A total of 30 cetacean and four pinniped species are known to or could occur in the study area (Table 3; see Waring et al. 2007). Several species are listed as ***Endangered*** under the ESA: the North Atlantic right, humpback, sei, fin, blue, and sperm whales. The Western North Atlantic Coastal Morphotype Stock of common bottlenose dolphins is listed as ***Depleted*** under the MMPA.

The marine mammals that occur in the proposed study area belong to three taxonomic groups: odontocetes (toothed whales, such as sperm and beaked whales or dolphins), mysticetes (baleen whales), and pinnipeds (seals and sea lions). Twenty-eight odontocetes and seven mysticetes may occur in the study area, and several are common in the study area (see below). Of the four species of pinnipeds that could potentially occur along the U.S. northeast coast, only the harbor and gray seals regularly inhabit the region. However, very few, if any, seals are expected to occur in the study area in summer.

(1) 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). It is listed as ***Endangered*** under the U.S. ESA (Waring et al. 2007) and on the 2008 IUCN Red List of Threatened Species (IUCN 2008), and is listed in CITES Appendix I (UNEP-WCMC 2008). Historically, right whale populations were severely depleted by commercial whaling. More recently, the 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).

TABLE 3. The habitat, occurrence, regional population sizes, and conservation status of marine mammals that could occur in or near the proposed study area in the northwest Atlantic Ocean.

Species	Habitat	Occurrence in Study Area	Regional Best Abundance Est. (CV)[1]	ESA[2]	IUCN[3]	CITES[4]
Mysticetes North Atlantic right whale (*Eubalaena glacialis*)	Coastal and shelf waters	Common	325 (0)[5]	EN	EN	I
Humpback whale (*Megaptera novaengliae*)	Mainly nearshore waters and banks	Common	11,570[6]	EN	LC	I
Minke whale (*Balaenoptera acutorostrata*)	Coastal waters	Common	~188,000[7]	NL	LC	I
Bryde's whale (*Balaenoptera brydei*)	Primarily offshore, pelagic	Rare	N.A.	NL	DD	I
Sei whale (*Balaenoptera borealis*)	Primarily offshore, pelagic	Uncommon	~10,300[8]	EN	EN	I
Fin whale (*Balaenoptera physalus*)	Continental slope, mostly pelagic	Common	~35,500[9]	EN	EN	I
Blue whale (*Balaenoptera musculus*)	Coastal, shelf, and coastal waters	Uncommon?	Up to 1400[10]	EN	EN	I
Odontocetes Sperm whale (*Physeter macrocephalus*)	Pelagic	Common?	13,190[11]	EN	VU	I
Pygmy sperm whale (*Kogia breviceps*)	Deep waters off the shelf	Uncommon	N.A.	NL	DD	II
Dwarf sperm whale (*Kogia sima*)	Deep waters off the shelf	Uncommon	N.A.	NL	DD	II
Cuvier's beaked whale (*Ziphius cavirostris*)	Pelagic	Uncommon	N.A.	NL	DD	II
Northern bottlenose whale (*Hyperoodon ampullatus*)	Pelagic	Rare	40,000[12]	NL	DD	II
True's beaked whale (*Mesoplodon mirus*)	Pelagic	Rare	N.A.	NL	DD	II
Gervais' beaked whale (*Mesoplodon europaeus*)	Pelagic	Rare	N.A.	NL	DD	II
Sowerby's beaked whale (*Mesoplodon bidens*)	Pelagic	Rare	N.A	NL	DD	II
Blainville's beaked whale (*Mesoplodon densirostris*)	Pelagic	Rare	N.A.	NL	DD	N.A.
Bottlenose dolphin (*Tursiops truncatus*)	Shelf, coastal, and offshore	Common	81,588 (0.17)[13]	NL^	LC	II
Pantropical spotted dolphin (*Stenella attenuata*)	Coastal and pelagic	Rare	N.A.	NL	LC	II
Atlantic spotted dolphin (*Stenella frontalis*)	Mainly coastal waters	Uncommon?	50,978 (0.42)	NL	DD	II
Spinner dolphin (*Stenella longirostris*)	Coastal and pelagic	Rare	N.A.	NL	DD	II
Striped dolphin (*Stenella coeruleoalba*)	Off the continental shelf	Common?	94,462 (0.40)	NL	LC	II
Short-beaked common dolphin (*Delphinus delphis*)	Continental shelf and pelagic	Common	120,743 (0.23)	NL	LC	II
White-beaked dolphin (*Lagenorhynchus albirostris*)	Continental shelf <200 m	Uncommon?	10s to 100s of 1000s[14]	NL	LC	II
Atlantic white-sided dolphin (*Lagenorhynchus acutus*)	Shelf and slope waters	Common	10s to 100s of 1000s[15]	NL	LC	II
Risso's dolphin (*Grampus griseus*)	Waters 400–1000 m	Common	20,479 (0.59)	NL	LC	II
False killer whale (*Pseudorca crassidens*)	Tropical, temperate, pelagic	Extralimital	N.A.	NL	DD	II

TABLE 3 (concluded).

Species	Habitat	Occurrence in Study Area	Regional Best Abundance Est. (CV)[1]	ESA[2]	IUCN[3]	CITES[4]
Killer whale (*Orcinus orca*)	Coastal, widely distributed	Rare	N.A.	NL*	DD	II
Long-finned pilot whale (*Globicephala melas*)	Mostly pelagic	Common?	~810,000[16]	NL	DD	II
Short-finned pilot whale (*Globicephala macrorhynchus*)	Mostly pelagic	Common?	~810,000[16]	NL	DD	II
Harbor porpoise (*Phoecena phocoena*)	Coastal	Common?	~500,000[17]	NL	LC	II
Pinnipeds Harbor seal (*Phoca vitulina*)	Coastal	Common	99,340 (0.097)	NL	LC	N.A.
Gray seal (*Halichoerus grypus*)	Coastal	Common	52,500[18]	NL	LC	N.A.
Harp seal (*Pagophilius groenlandicus*)	Coastal	Uncommon	5.5 million[19]	NL	LC	N.A.
Hooded seal (*Cystophora cristata*)	Coastal	Uncommon	592,100[20]	NL	VU	N.A.

N.A. = Data not available or species status was not assessed. ? indicates uncertainty

[1] Abundance estimates are given from Waring et al. (2007), typically for U.S. Western North Atlantic stocks unless otherwise indicated; CV (coefficient of variation) is a measure of a number's uncertainty on a proportional basis. For species whose distribution is primarily offshore or not known, we do not consider estimates for the U.S. EEZ in Waring et al. (2007) to be valid estimates for the NWA and the regional population is given as N.A. unless it is available from another source.

[2] U.S. Endangered Species Act; EN = Endangered, NL = Not listed

[3] Codes for IUCN classifications from the 2008 IUCN *Red List of Threatened Species* (IUCN 2008): CR = Critically Endangered; EN = Endangered; VU = Vulnerable; NT = Near Threatened; LC = Least Concern; DD = Data Deficient.

[4] Convention on International Trade in Endangered Species of Wild Fauna and Flora (UNEP-WCMC 2008): Appendix I = Threatened with extinction; Appendix II = not necessarily now threatened with extinction but may become so unless trade is closely controlled.

[5] Estimate updated in NMFS 2008 Draft stock assessment report, available at http://www.nmfs.noaa.gov/pr/pdfs/sars/ao2008_draft_summary.pdf.

[6] Estimate for the western North Atlantic (IWC 2007a).

[7] Estimate for the North Atlantic (IWC 2007; Waring et al. 2007).

[8] Estimate for the Northeast Atlantic (Cattanach et al. 1993).

[9] Estimate for the North Atlantic (IWC 2007a; Waring et al. 2007).

[10] Estimate for the North Atlantic (NMFS 1998).

[11] Estimate for North Atlantic (Whitehead 2002).

[12] Estimate for Northeast Atlantic (NAMMCO 1995: 77).

[13] Estimate for the Western North Atlantic and Offshore stock, and may include coastal forms. 43,951 animals estimated for all management units of the Coastal morphotype (Waring et al. 2007).

[14] Tens to low hundreds of thousands (Reeves et al. 1999a).

[15] High tens to low hundreds of thousands (Reeves et al. 1999b).

[16] Estimate may include both long- and short-finned pilot whales.

[17] Estimate for the North Atlantic (Jefferson et al. 2008).

[18] Estimate for the northwest Atlantic Ocean in the Gulf of St. Lawrence and along the Nova Scotia eastern shore (Hammill 2005).

[19] Estimate for the northwest Atlantic Ocean (DFO 2007).

[20] Estimate for the northwest Atlantic Ocean (ICES 2006).

* Killer whales in the eastern Pacific Ocean, near Washington state, are listed as endangered under the U.S. ESA but not in the Atlantic Ocean.

^ The Western North Atlantic Coastal Morphotype stock, ranging from NJ to FL, is listed as depleted under the U.S. Marine Mammal Protection Act.

The western North Atlantic right whale minimum population size is estimated at 325 based on individual photo-identification in 2003. No estimate of abundance with an associated coefficient of variation has been calculated for this population (Waring et al. 2007). The trend in population growth rate for the North Atlantic right whale was under some debate, with evidence of modest population growth rate for the period 1986–1992 (Knowlton et al. 1994) but declining survival probability and increased mortality in the late 1990s (Caswell et al. 1999; Fujiwara and Caswell 2001; Clapham 2002; Kraus et al. 2005). There is recent evidence of significant increase in the minimum number of animals known to be alive and a slight mean population growth of 1.8% for the period 1990–2003 (Waring et al. 2007).

The general distribution of North Atlantic right whales encompasses continental shelf waters off the eastern U.S. and Canada, from Florida to Nova Scotia (Winn et al. 1986). 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 recently sighted (Moore and Clarke 1963; Winn et al. 1986; Knowlton et al. 1992; IWC 2001; NEAQ 2006).

There are five well-known habitats in the Northwest Atlantic used annually by right whales (Winn et al. 1986; NMFS 2005a). These include the winter calving grounds in coastal waters of the southeastern U.S. (Florida/Georgia); spring feeding grounds in the Great South Channel (east of Cape Cod); late winter/spring feeding grounds and nursery grounds in Massachusetts Bay and Cape Cod Bay; summer/fall feeding and nursery grounds in the Bay of Fundy; and summer/fall feeding grounds on the Nova Scotian Shelf.

The first three habitats were designated as critical by the National Marine Fisheries Service (NMFS 1994). 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 considered to include "high use" areas, yet the whales clearly 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). 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).

There is a general seasonal north-south migration of the North Atlantic population, but right whales might be seen anywhere off the Atlantic U.S. throughout the year (Gaskin 1982). The population generally migrates as two separate components. Pregnant females and some juveniles migrate from the northern feeding grounds to the calving grounds off the southeastern U.S. in late fall–winter. Mothers and calves return northward to the feeding grounds in late winter to early spring. The majority of the right whale population is unaccounted for on the southeastern U.S. winter calving ground, and not all reproductively-active females return to the area each year (Kraus et al. 1986; Winn et al. 1986; Kenney et al. 2001). 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 when the cow-calf pairs return. Other wintering areas have been suggested, based upon sparse data or historical whaling logbooks; these include the Gulf of St. Lawrence, Newfoundland and Labrador, the coast of New York and New Jersey, Bermuda, and Mexico (Payne and McVay 1971; Aguilar 1986; Mead 1986; Lien et al. 1989; Knowlton et al. 1992).

North Atlantic right whales are found commonly on the northern feeding grounds off the northeastern United States during early spring and summer. Highest abundance in Cape Cod bay is in February and April (Winn et al. 1986; Hamilton and Mayo 1990) and from April to June in the Great South Channel east of Cape Cod (Winn et al. 1986; Kenney et al. 1995). Throughout the remainder of summer and into fall (June through November), North Atlantic right whales are most commonly seen farther north on feeding grounds in Canadian waters, with peak abundance during August, September, and early October (Gaskin 1987, 1991).

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 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).

The seasonal occurrence of right whales in mid-Atlantic waters is mostly between November and April, with peaks in December, March, and April, when whales transit through the area on their migrations to and from breeding grounds or feeding grounds (Knowlton 1997). An adult female fitted with a transmitter in July 2000 on the northern feeding grounds off New Brunswick migrated along the mid-Atlantic corridor at a steady pace of about 3.5 km/hr, arriving in December in the Southeast Critical Habitat Area (ONR 2000). This represents the longest tracking of a right whale (130 days).

Knowlton et al. (2002) provided an extensive and detailed analysis of survey data, satellite tag data, whale strandings, and opportunistic sightings along State waters of the mid-Atlantic migratory corridor[1], from the border of Georgia/South Carolina to south of New England, including waters in the proposed seismic survey area off MV. 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). Water depth preference was for shallow waters; 80% of all sightings were in depths <27 m, and 93% were in depths <45 m (Knowlton et al. 2002). Most sightings farther than 56 km from shore occurred at the northern end of the corridor, off New York and south of New England.

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

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

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[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 Wilmington (UNCW), Continental Shelf Associates, Cetacean and Turtle Assessment Program (CETAP), NOAA, and University of Rhode Island.

All age classes and sexes can be found in all habitats, although there is strong segregation by sex on the southeast winter calving ground, where most sightings are of females with calves and some juveniles (Kraus 1993; Hamilton et al. 2007).

Right whales are generally not gregarious, usually occurring singly or in small transitory groups (Reeves et al. 2002). Along the mid-Atlantic corridor, they are usually found traveling alone (Kraus et al. 1993), whereas in prime feeding habitat, aggregations of up to 150 can be sighted (Reeves et al. 2002). Right whale courtship groups of 2–35 can be found on summer and fall feeding grounds, and on occasion, large groups of adult males can be found in the southeast (Kraus and Hatch 2001; Reeves et al. 2002).

Right whales are slow swimmers. Whales satellite-tagged in the Bay of Fundy during August and September traveled at speeds between 0.8 km/h and 4.6 km/h (Mate et al. 1997). Based on photographic re-identifications, whales traveling along the mid-Atlantic migratory corridor migrated at a mean swim rate of 3.2 km/h (Firestone et al. 2008).

Right whale feeding can occur at the surface (skim-feeding) or throughout the water column; foraging in high-use areas is frequently down to the bottom (Watkins and Schevill 1979; Goodyear 1993; Winn et al. 1986; Mate et al. 1997; Baumgartner et al. 2003b). Feeding dives are characterized by rapid descent to depths of 80–175 m for 5–14 min, and then rapid ascent back to the surface (Goodyear 1993; Baumgartner and Mate 2003). Mother/calf pairs have shorter dive dives and longer surface intervals than single whales, suggesting that they could be more at risk of ship collisions (Kraus et al. 1993; Baumgartner and Mate 2003).

Right whales must locate and exploit very dense patches of prey (zooplankton) in order to feed efficiently (Mayo and Marx 1990). Temporal and spatial formations of zooplankton concentrations have been correlated with shifts in the distribution of right whales on feeding grounds (Brown and Winn 1989). Shifts in copepod abundance are thought to have a tremendous significance to the North Atlantic right whale population, as calving rates have been linked to the abundance of prey; the calving rate remained stable when the abundance of the copepod *Calanus* was high, but it fell when the abundance of *Calanus* declined in the late 1990s (Greene et al. 2003).

Shelf waters off MV in Survey Area.—A review of the mid-Atlantic whale sighting and tracking data archive for the mid Atlantic from 1974 to 2002 found a high density of North Atlantic right whale sightings in the proposed seismic survey area in March and April, few right whale sightings in January, February, June, July, September, October, and December, and no sighting records for May, August, and November (Beaudin Ring 2002). The North Atlantic Right Whale Consortium database contains only 3 sightings during August (all in 2004) for a block (39.5–41.5ºN, 69.5–71ºW) that contains the proposed survey area (Right Whale Consortium 2009); all were just east of Nantucket Shoals. Palka (2006) reviewed North Atlantic right whale density in the U.S. Navy Northeast Operating Area (NE OPERA) based on summer abundance surveys conducted during 1998–2004. One of the lowest whale densities (including right whales) was found in the Georges Bank West stratum, which includes most of the proposed seismic survey area. However, survey effort for this stratum was also the lowest; only two surveys were conducted, one aerial survey from 19 July to 16 August 2002 and another from 12 June to 12 July 2004. No right whales were sighted.

North Atlantic right whales likely travel through the proposed seismic survey area in the month of August only occasionally. In 2001, a tagged entangled right whale traveled south from Georges Bank to New York and back; on 28 August, it was reported 67 km southeast of MV, and two days later, it was reported farther north, in the Great South Channel (Whalenet 2008).

Federal and Other Action.—In 2002, NMFS received a petition to revise and expand the designation of critical habitat for this species. The revision was declined and the critical habitat designated in

1994 remains in place (NMFS 2005). The designation of critical habitat doesn't 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.

In an effort to reduce ship collisions with North Atlantic right whales, the Right Whale Sighting Advisory System (EWS; early warning system) was instigated to alert area ship traffic to the presence of right whales in the critical calving habitat in the southeastern U.S. The jointly funded aerial survey program, initiated in 1993, is designed to obtain accurate, current information on the locations of whales and continuously updated sighting information is immediately relayed to mariners in the area. This system was extended to the feeding areas off New England in 1996 (NMFS NEFSC 2008).

In 1999, a Mandatory Ship Reporting System was implemented by the U.S. Coast Guard (USCG 1999; 2001). This reporting system requires specified vessels (larger than 300 gross registered tons) to report their location while in the right whale nursery and feeding areas (Ward-Geiger et al. 2005). Mandatory ship reporting takes place from 15 November to 15 April in the southeastern U.S., in coastal waters within ~46 km of shore along a 167-km stretch of coast in Florida and Georgia. In the northeastern U.S., the reporting system is year-round and the geographical boundaries include the waters of Cape Cod Bay, Massachusetts Bay, and the Great South Channel.

In November 2006, NOAA established recommended shipping routes in key right whale aggregation areas at the entrances to three ports in Georgia and Florida from November through April, and in Cape Cod Bay from January to May (NOAA 2006). In July 2007, the Boston Traffic Separation Scheme (TSS) was realigned by a 12º shift in the northern leg, and the two traffic lanes were narrowed by 0.8 km each in an effort to reduce ship strike risk to right whales (NOAA 2007).

On 9 December 2008 NMFS established regulations to implement a uniform mandatory vessel speed restriction of 18.5 km or less for all vessels 20 m or longer in specific locations (Seasonal Management Areas or SMAs) along the U.S. east coast during times when whales are likely present (NOAA 2008). The speed restrictions extend out to ~37 km around the major ports along the mid-Atlantic corridor. The restriction applies during 15 November–15 April in the southeast calving grounds, 1 January–15 May in Cape Cod Bay, 1 March–30 April off Race Point at the northern end of Cape Cod, 1 April–31 July in the Great South Channel, and 1 November–30 April near entrances to several ports along the mid-Atlantic corridor. The closest SMA to the proposed survey area, the Block Island Sound SMA, is located to the west of the northern part of the survey area.

NOAA may also establish Dynamically Managed Areas (DMAs), which would be established temporarily in direct response to actual whale sightings. Mariners are encouraged to avoid these areas or reduce speeds to 18.5 km or less while transiting through these areas. The size of a DMA would be determined by the number of whales sighted. Once an area has been designated, the rule stays in effect for 15 days and may be extended for a further 15 days if whales remain in the area (NOAA 2008).

Humpback whale (*Megaptera novaengliae*)

The humpback whale is cosmopolitan in distribution; it migrates between coastal waters in high latitudes, where it forages during summer months, and the tropics, where it breeds in winter months (Jefferson et al. 2008). The humpback whale is listed as ***Endangered*** under the ESA and ***Least Concern*** on the 2008 IUCN Red List of Threatened Species (IUCN 2008). Historical commercial whaling of humpback whales drastically decreased their numbers worldwide, but protection since 1964 has not brought numbers back to more than 10% of pre-exploitation levels. In the NWA, humpbacks feed during spring, summer, and fall in areas ranging from Cape Cod to Newfoundland. A Gulf of Maine stock is recognized off the northeastern U.S. coast as a genetically isolated feeding stock in the North Atlantic (Palsboll et al. 2001). The best abundance estimate for the entire North Atlantic is 11,570, and 847 whales are estimated to comprise the Gulf of Maine stock (Waring et al. 2007).

Single animals or groups of 2–3 are commonly observed, but much larger groups can occur on foraging and breeding grounds (Clapham 2000). Humpbacks appear to use deep, offshore migratory corridors between coastal and nearshore foraging and breeding grounds. During winter, whales from most of the Atlantic feeding areas are found in the West Indies for mating and calving, and apparently genetic mixing among subpopulations occurs (Clapham et al. 1993; Stevick et al. 1998). Some whales do not migrate to the West Indies every winter, and lower densities of humpbacks can be found in mid- and high-latitudes during this time (Clapham et al. 1993).

Movements of humpbacks within the Gulf of Maine have been strongly associated with the relative abundance of herring and sandlance (Stevick et al. 2006). Humpbacks favor shallow banks and shoals or areas with high seafloor relief (Hamazaki 2002), and associate with thermal fronts (Doniol-Valcroze et al. 2007). The highest numbers of humpback whales in New England waters occurs from mid-April to mid-November, and they can be found near Stellwagen Bank, Jeffreys Ledge, the Great South Channel, the edges and shoals of Georges Bank, Cashes Ledge, and northeast into Nova Scotia and Newfoundland waters (DoN 2005; Waring et al. 2007). Greatest concentrations of humpback whales in spring occur in the western and southern edges of the Gulf of Maine. During summer, their greatest concentrations are found throughout the Gulf of Maine, east of Cape Cod, and near the coast from Long Island to northern Virginia. Similar distribution patterns are seen in the fall, although sightings south of Cape Cod Bay are less frequent than those near the Gulf of Maine. From December to March, there are few occurrences of humpback whales over the continental shelf of the Gulf of Maine, and in Cape Cod and Massachusetts Bay (Clapham et al. 1993; DoN 2005). Low numbers of humpbacks are thought to remain during the winter over the continental shelf from the Gulf of Maine to Georges Bank (DoN 2005).

Minke whale (*Balaenoptera acutorostrata*)

The minke whale has a cosmopolitan distribution that spans polar, temperate, and tropical regions (Jefferson et al. 2008). Four populations are recognized in the North Atlantic, including the Canadian East Coast stock that ranges from the eastern U.S. coast to the eastern half of Davis Strait (Waring et al. 2007). The best abundance estimate for the Canadian East Coast stock of minke whales is 3312. The populations of the Northeastern and Central Atlantic and West Greenland stocks are estimated to be 174,000 and 10,800, respectively (IWC 2007a), for a total of ~188,000 animals in the North Atlantic.

The minke whale is a small baleen whale and tends to be solitary or in groups of 2–3, but can occur in much larger aggregations around prey resources (Jefferson et al. 2008). Its small size, inconspicuous blows, and brief surfacings make the minke whale difficult to detect at sea, but it is also known to approach vessels at times (Stewart and Leatherwood 1985). Minke whales feed primarily on small schooling fish in the western North Atlantic, generally occupy waters over the continental shelf, and are known to make short-duration dives (Stewart and Leatherwood 1985).

Minke whales are common off the U.S. east coast over continental slope and shelf waters. They also appear to associate with thermal fronts (Doniol-Valcroze et al. 2007). Some seasonal movements are apparent in many regions, and movement patterns likely mirror the abundance and distribution of their primary prey species (Macleod et al. 2004a). Seasonal movements in the NWA are apparent, with animals moving south and offshore from New England waters during the winter; the highest numbers sighted are during spring and summer, with fewer records during fall (DoN 2005; Waring et al. 2007).

Bryde's whale (*Balaenoptera brydei*)

Bryde's whale has a circumpolar distribution, typically between 40ºN and 40ºS (Jefferson et al. 2008). The distribution of Bryde's whale is not well known, but in the NWA, it most frequently occurs in or near the Gulf of Mexico. Bryde's whale is not included in the 2007 stock assessment for the North Atlantic (Waring et al. 2007).

Bryde's whales can be observed in offshore and coastal areas, but tend to be associated with areas of unusually high productivity (Jefferson et al. 2008). Other than a single stranding in Chesapeake Bay, there are no records of Bryde's whales north of NC, and any animals in the NWA would be considered strays (Mead 1977). Thus, sightings of Bryde's whales in the proposed study area are not expected.

Sei whale (*Balaenoptera borealis*)

The distribution of the sei whale is not well known, but it is found in all oceans and appears to prefer mid-latitude temperate waters (Jefferson et al. 2008). The species is listed as ***Endangered*** under the ESA and on the 2008 IUCN Red List of Threatened Species (IUCN 2008), and is listed in CITES Appendix I (UNEP-WCMC 2008). The species is poorly known because of confusion with Bryde's whales and unpredictable distribution patterns, such that it may be common in an area for several years and then seemingly disappear (Schilling et al. 1992; Jefferson et al. 2008). Two stocks are recognized in the 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. 2007). The best abundance estimate for the Nova Scotia stock is 207 (Waring et al. 2007). Cattanach et al. (1993) estimated a total of ~10,300 sei whales for the Northeast Atlantic.

Sei whales are pelagic, and generally are not found in coastal waters (Harwood and Wilson 2001). They are found in deeper waters characteristic of the continental shelf edge region (Hain et al. 1985), and appear to prefer regions of steep bathymetric relief such as the continental shelf break, seamounts, and canyons (Kenney and Winn 1987; Gregr and Trites 2001). On feeding grounds, they associate with oceanic frontal systems (Horwood 1987) such as the cold eastern currents in the North Pacific (Perry et al. 1999). Sei whales are frequently seen in groups of 2–5 (Jefferson et al. 2008), although larger groups sometimes form on feeding grounds (Gambell 1985a). Sei whales generally do not dive deeply, and dive durations are 15 min or longer (Gambell 1985a).

The southern portion of the Nova Scotia stock's range includes the Gulf of Maine and Georges Bank during spring and summer (Waring et al. 2007). Peak sightings occur in spring and are concentrated along the eastern edge of Georges Bank into the Northeast Channel and the southwestern edge of Georges Bank (DoN 2005; Waring et al. 2007). 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. Aerial surveys detected several sei whales near the continental shelf edge region south of Nantucket in the spring of 2001, and rare sei whales sightings occur from Cape Cod south to Florida in winter (Mitchell and Chapman 1977; Waring et al. 2007). During summer and fall, most sei whales sightings were in feeding grounds in the Bay of Fundy and on the Scotian Shelf; sightings south of Cape Cod were rare (Table B-6a in DoN 2005). Thus, sightings of sei whales in the proposed study area are not expected.

Fin whale (*Balaenoptera physalus*)

The fin whale is widely distributed in all the world's oceans (Gambell 1985b), but typically occurs in temperate and polar regions from 20° to 70° north and south of the equator (Perry et al. 1999). It is listed as ***Endangered*** under the U.S. ESA and on the 2008 IUCN Red List of Threatened Species (IUCN 2008), and is listed in CITES Appendix I (UNEP-WCMC 2008). The current best available population estimates are 2269 for the western North Atlantic (Waring et al. 2007) and 30,000 and 3200 for the Central/Northeastern and West Greenland, respectively (IWC 2007a), for a total of ~35,500 in the North Atlantic.

Fin whales eat euphausids and small fish (Borobia et al. 1995) and tend to concentrate in areas near thermal fronts or shallow areas with high topographic variation that help to mix and stratify the water column (Woodley and Gaskin 1996; Doniol-Valcroze et al. 2007). They can be found as individuals or groups of 2–7, but can form much larger feeding aggregations, sometimes with humpback and minke whales (Jefferson et al. 2008). Foraging fin whales reach mean dive depths and times of 98 m and 6.3 min, respectively, while recorded mean dive depths and times for non-foraging fin whales in the Pacific are 59 m and 4.2 min, respectively (Croll et al. 2001).

It is debatable whether all fin whales in the North Atlantic undergo annual migrations between warm water breeding grounds and cool water foraging areas, and current year-round monitoring of fin whale calls provide no evidence for such large-scale movements (Watkins et al. 2000). Fin whales are present in U.S. shelf waters during the winter, and are sighted more frequently than any other large whale at this time (DoN 2005). However, it is possible that fin whales undergo migrations into Canadian waters, open-ocean areas, and potentially subtropical or tropical regions (Waring et al. 2007). Clark (1995) reported a southward migration of whales in the fall from Newfoundland south past Bermuda, and into the West Indies.

Fin whales occur year-round in New England continental shelf waters (Waring et al. 2007). Winter sightings are most concentrated around Georges Bank and in Cape Cod Bay. During summer, most fin whale sightings are north of 40ºN, with concentrations in the Gulf of Maine, Great South Channel, and Georges Basin, and smaller numbers on the shelf south of there (Figure B-8a in DoN 2005). During fall, almost all fin whales move out of U.S. waters to feeding grounds in the Bay of Fundy and on the Scotian Shelf or remain at Stellwagen Bank and Murray Basin (Figure B-8a in DoN 2005), or begin a southward migration (Clark 1995).

Blue whale (*Balaenoptera musculus*)

The blue whale has a cosmopolitan distribution, and tends to be pelagic, only coming nearshore to feed and possibly to breed (Jefferson et al. 2008). It is listed as ***Endangered*** under the U.S. ESA and on the 2008 IUCN Red List of Threatened Species (IUCN 2008), and is listed in CITES Appendix I (UNEP-WCMC 2008). All blue whale populations have been exploited commercially, and many have been severely depleted as a result. The worldwide population has been estimated at 15,000, with 10,000 in the Southern Hemisphere (Gambell 1976), 3500 in the North Pacific, and up to 1400 in the North Atlantic (NMFS 1998a).

In the western North Atlantic, the distribution of the blue whale extends as far north as Davis Strait and Baffin Bay (Sears 2002). Little is known about the movements and wintering grounds of the stocks (Mizroch et al. 1984). Two strandings of blue whales have been reported from the Gulf of Mexico (Baughman 1946; Lowery 1974 *in* Sears and Calambokidis 2002). The acoustic detection of blue whale, using the U.S. Navy's Sound Surveillance System (SOSUS) program, has tracked blue whales throughout most of the North Atlantic, including deep waters east of the U.S. Atlantic Exclusive Economic Zone (EEZ) and subtropical waters north of the West Indies (Clark 1995).

Wenzel et al. (1988) reported the occurrence of three blue whales in the Gulf of Maine in 1986 and 1987, which were the only reports of blue whales in shelf waters from Cape Hatteras to Nova Scotia, where sighting coverage was intensive since 1979, and suggested that it is unlikely that blue whales occur regularly in the shelf waters off the U.S. east coast. Waring et al. (2007) suggested that "the blue whale is best considered as an occasional visitor in U.S. Atlantic Exclusive Economic Zone (EEZ) waters". Sightings of blue whales in the proposed study are not expected.

(2) Odontocetes

Sperm Whale (*Physeter macrocephalus*)

The sperm whale is the largest of the toothed whales, with an extensive worldwide distribution (Jefferson et al. 2008). This species is listed as ***Endangered*** under the ESA, but on a worldwide basis it is abundant and not biologically endangered. It is listed as ***Vulnerable*** on the 2008 IUCN Red List of Threatened Species (IUCN 2008) and is listed in CITES Appendix I (UNEP-WCMC 2008). Rice (1989) estimated the North Atlantic population at ~190,000, whereas Whitehead (2002) estimated the population of the Iceland-Faeroes area, the area to the northeast of it, and the U.S east coast at 13,190.

Sperm whales range as far north and south as the edges of the polar pack ice, although they are most abundant in tropical and temperate waters where temperatures are >15ºC (Jefferson et al. 2008). Sperm whale distribution and relative abundance can vary in response to prey availability, most notably mesopelagic and benthic squid (Jaquet and Gendron 2002). Sperm whales undertake some of the deepest-known dives for the longest durations among cetaceans. They can dive as deep as ~2 km and possibly deeper on rare occasions, for periods of over 1 h; however, most of their foraging occurs at depths of ~300–800 m during dives ranging 30–45 min (Whitehead 2003). Distribution of sperm whales can also be linked to social structure. Sperm whales occur singly (older males) or in groups, with a mean group size of 20–30 (Whitehead 2003). Groups of adult females and juveniles generally occur in warm waters, whereas males are commonly alone or in same-sex aggregations of 10–30 males, often occurring in higher latitudes outside of the breeding season (Letteval et al. 2002; Whitehead 2003).

In the NWA, 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 NWA (Waring et al. 2001). Off the eastern U.S. coast, they are also known to concentrate in regions with well-developed temperature gradients, such as along the edges of the Gulf Stream and warm core rings, which may aggregate their primary prey, squid (Jaquet 1996). Sperm whales appear to have a well-defined seasonal cycle in the NWA. In winter, most historical records are in waters east and northeast of Cape Hatteras, with few animals north of 40ºN; in spring, they shift the center of their distribution northward to areas east of Delaware and Virginia, but they are widespread throughout the central area of the MAB and southern tip of Georges Bank. During summer, they expand their spring distribution to include areas east and north of Georges Bank, the Northeast Channel, and the continental shelf south of New England (inshore of 100 m deep). By fall, sperm whales are most common south of New England on the continental shelf but also along the shelf edge in the MAB (Watkins et al. 2007). Based on mapping of sperm whale records in the NWA, it appears that sperm whales generally do not occur north of 40ºN in fall and winter and, for all seasons, sperm whales tend to occur in deep water and over or beyond the continental slope (DoN 2005). Because of the sperm whale's preference for deep, offshore waters, sightings of sperm whales in the proposed study area are not expected.

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

Pygmy and dwarf sperm whales are distributed widely throughout tropical and temperate seas, but their precise distributions are not well known as most information on these species comes from strandings (Jefferson et al. 2008). They are difficult to sight at sea, perhaps because of their avoidance reactions to ships and behavior changes in relation to survey aircraft (Würsig et al. 1998). Additionally, the two species are difficult to distinguish from one another when sighted (Jefferson et al. 2008). During sighting surveys and, hence, in population and density estimates, the two species are most often categorized together as *Kogia* spp. (Waring et al. 2007). Abundance estimates for these largely offshore species in the NWA are not available.

Both species inhabit deep waters along the continental shelf and slope, where they feed mainly on various species of squid, crustaceans, and fish (McAlpine et al. 1997; Reeves et al. 1999c; McAlpine 2002). 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. 2004b). Barros et al. (1998), on the other hand, suggested that dwarf sperm whales might be more pelagic and dive deeper than pygmy sperm whales. Another suggestion is 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 ETP (Wade and Gerrodette 1993).

Although both species have often been sighted alone, pygmy and dwarf sperm whales occur in groups of up to 6 and 10, respectively (Caldwell and Caldwell 1989). In the Gulf of California, median dive time for dwarf or unidentified sperm whales was 8.6 min and median surface time was 1.2 min, and dives of up to 25 min and surface times up to 3 min were common (J. Barlow, pers. comm. *in* Willis and Baird 1998).

In the NWA, both species are thought to occur as far north as the Canadian east coast, with the pygmy sperm whale ranging as far as southern Labrador; both species prefer offshore waters (Jefferson et al. 2008. Between 1999 and 2003, 125 pygmy and 37 dwarf sperm whales strandings were recorded from Nova Scotia to Puerto Rico (Waring et al. 2007), mostly off the southeastern U.S. coast. Previous stranding records during 1990–1998 also indicate that pygmy and dwarf sperm whale strandings occur more commonly along the coast from North Carolina to Florida (194 and 43 strandings, respectively) than along the coast of the northeastern states (21 and 3 strandings, respectively; Barros et al. 1998). Sightings of dwarf or pygmy sperm whales in the proposed study area are not expected.

Cuvier's Beaked Whale (*Ziphius cavirostris*)

Cuvier's beaked whale is probably the most widespread of the beaked whales, although it is not found in polar waters (Jefferson et al. 2008). It is occasionally observed at sea and is mostly known from strandings. Its inconspicuous blows, deep-diving behavior, and tendency to avoid vessels all help to explain the infrequent sightings (Barlow and Gisiner 2006). Cuvier's beaked whale is not listed under the ESA, but the Western North Atlantic Stock is considered a strategic stock because of uncertainty regarding stock size and evidence of human-induced mortality and serious injury associated with acoustic activities (Waring et al. 2007). Abundance estimates for this largely offshore species in the NWA are not available.

Cuvier's beaked whale is an offshore, deep-diving species that feeds almost exclusively on large-bodied squid (MacLeod et al. 2003). Deep dives last a median duration of 28.6 min followed by surfacings lasting a median duration of 126 s (MacLeod and D'Amico 2006). Adult males of this species usually travel alone, but these whales can be seen in groups of up to 15, with a mean group size of 2.3 (MacLeod and D'Amico 2006).

In the NWA, Cuvier's beaked whales have stranded and been sighted as far north as the Nova Scotian shelf and occur most commonly from Massachusetts to Florida (MacLeod et al. 2006). Most sightings in the NWA occur in late spring or summer, particularly along the continental shelf edge in the mid-Atlantic region (Waring et al. 2001, 2007). Mapping of combined beaked whale sightings in the NWA suggests that beaked whales are rare in winter and fall, uncommon in spring, and abundant in summer in waters north of Virginia, off the shelf break and over the continental slope and areas of high relief (DoN 2005). Sightings of Cuvier's beaked whales in the proposed study area are not expected. .

Northern bottlenose whale (*Hyperoodon ampullatus*)

Northern bottlenose whales are considered extremely uncommon within waters of the U.S. Atlantic EEZ, but have two primary areas of known concentration in Canadian waters: "The Gully" just north of Sable Island, Nova Scotia, and Davis Strait off northern Labrador (Reeves et al. 1993; Waring et al. 2007). They range from the NWA off New England to subarctic waters, with only two sightings made in 1993 and 1996 along the southern edge of Georges Bank (MacLeod and D'Amico 2006; Waring et al. 2007). Abundance estimates for this largely offshore species in the NWA are not available, although there are ~40,000 bottlenose whales estimated in the Northeast Atlantic (NAMMCO 1995:77).

Northern bottlenose whales are deep divers, and animals tagged off Nova Scotia dove every ~80 min to over 800 m, with a maximum dive depth of 1453 m (Hooker and Baird 1999). They forage primarily on large-bodied squid (MacLeod et al. 2003) and travel in groups of 1–22 (average 3.6) that may consist of individuals of different age and sex classes (MacLeod and D'Amico 2006).

Sightings of northern bottlenose whales in the proposed study area are not expected.

Mesoplodon spp.

Four species of beaked whales from the genus *Mesoplodon* occur in the NWA, known almost entirely from stranding records: True's beaked whale (*M. mirus*), Gervais' beaked whale (*M. europaeus*), Sowerby's beaked whale (*M. bidens*), and Blainville's beaked whale (*M. densirostris*). The cryptic behavior, small group sizes, and short surface durations of these species make them difficult to observe and identify at sea, and stock structure for each of these species is currently unknown (MacLeod 2000; Waring et al. 2007; Jefferson et al. 2008). *Mesoplodon* spp. are not listed under the ESA, but they are considered as a cumulative strategic stock because of uncertainty regarding stock size and evidence of human induced mortality and serious injury associated with acoustic activities (Waring et al. 2007). The best abundance estimate for grouped beaked whales (*Ziphius* and *Mesoplodon* spp.) off the U.S. east coast is 3513 animals, including 2839 animals from the northern U.S. Atlantic (Waring et al. 2007). Abundance estimates for these largely offshore species in the NWA are not available.

The different mesoplodont species are difficult to distinguish in the field, and are most often categorized as *Mesoplodon* spp. during sighting surveys, and therefore in density and population estimates. Almost everything that is known regarding most of the species has come from stranded animals (Pitman 2002). They are all thought to be deep-water animals (e.g., Davis et al. 1998) that tend to inhabit shelf-edge habitat associated with underwater canyons, and are only rarely seen over the continental shelf (Waring et al. 2001). Typical group sizes are 1–6 (Pitman 2002). Based on limited information, *Mesoplodon* spp. appear to feed on mesopelagic (200–1000 m) squid and fish (Mead 1989b).

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. Group size is up to three (Jefferson et al. 2008).

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 whale is much more common in the western Atlantic (40 strandings on the U.S east coast) than in the eastern Atlantic (2 records), and off the U.S. east coast, it occurs from Cape Cod Bay, Massachusetts (Moore et al. 2004) to Florida, with a few records in the Gulf of Mexico (Mead 1989b).

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; a stranding on the west coast of Florida is thought to be a stray (MacLeod et al. 2006). Off the coast of Nova Scotia, Sowerby's beaked whales observed during 1997 and 1998 in water depths 550–1500 m were in groups of 3–10, and dives were 12–28 min in duration (Hooker and Baird 1999).

Blainville's Beaked Whale (M. densirostris).—Blainville's beaked whale is the *Mesoplodon* species with the widest distribution throughout the world in tropical and warm temperate waters (Mead 1989b). Occasional occurrences in cooler, higher-latitude waters are presumably related to warm-water incursions such as the Gulf Stream (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). The most commonly observed group size for this species is 1–2, with a maximum of 9 off Hawaii (Baird et al. 2004; Jefferson et al. 2008). MacLeod and D'Amico (2006) reported a mean group size of 3.5 (n = 31), and Ritter and Brederlau (1999) reported a mean group size of 3.4. Two Blainville's beaked whales tagged off Hawaii made long (>50 min), deep (>800 m; maximum 1408 m) dives at ~2-h intervals, often alternating with several shorter dives to 100–200 m or <50 m, or numerous "inter-ventilation" dives to 2–4 m (Baird et al. 2006).

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.

Sightings of *Mesoplodon* spp. in the proposed study area are not expected.

Bottlenose dolphin (*Tursiops truncatus*)

The bottlenose dolphin is distributed almost worldwide in temperate and tropical waters. In the Northwest Atlantic, it occurs from Nova Scotia to Florida, the Gulf of Mexico and the Caribbean, and south to Brazil (Würsig et al. 2000). There are two morphologically and genetically distinct bottlenose dolphin morphotypes: a shallow-water form mainly found in coastal waters, and a deep-water form mainly found in oceanic waters (Duffield et al. 1983; Mead and Potter 1995; Hoelzel et al. 1998; Walker et al. 1999). As well as inhabiting different areas, these forms differ in their diving abilities (Klatsky 2004) and prey types (Mead and Potter 1995). Although not listed as threatened or endangered under the U.S. ESA, the western North Atlantic coastal migratory bottlenose dolphin stock is listed as ***depleted*** under the MMPA (NMFS 1993) and the seven currently recognized management units are considered strategic stocks (Waring et al. 2007). The best estimate for the western North Atlantic offshore stock is 81,588, and the sum of the estimates for the coastal management units is 43,951 (Waring et al. 2007)

Bottlenose dolphins occur in groups of 2–15, but can be observed offshore in groups of hundreds (Shane et al. 1986; Jefferson et al. 2008). They have a fluid and dynamic social organization, and group sizes are associated with habitat complexity and water depth; shallow-water areas tend to have smaller group sizes than open or pelagic regions (Shane et al. 1986; Connor et al. 2000). Although often seen in coastal areas, bottlenose dolphins can dive to depths up to 535 m for periods up to 12 min (Schreer and Kovacs 1997).

There are regional and seasonal differences in the distribution of the offshore and coastal forms of bottlenose dolphins off the U.S. east coast. Evidence of year-round or seasonal residents and migratory groups exist for the coastal form of bottlenose dolphins, with the so-called "northern migratory management unit" occurring north of Cape Hatteras to New Jersey, but only during summer and in waters <25 m deep (Waring et al. 2007). For all other management units and during other seasons, it is unlikely that coastal forms of bottlenose dolphins would occur near the proposed study area. The offshore form appears to be most abundant along the shelf break and is differentiated from the coastal form by occurring in waters typically >40 m deep (Waring et al. 2007). Bottlenose dolphin records in the NWA suggest that they generally can occur year-round from the continental shelf to deeper waters over the abyssal plain, from the Scotian Shelf to North Carolina (DoN 2005).

Pantropical Spotted Dolphin (*Stenella attenuata*)

As its name indicates, the pantropical spotted dolphin can be found throughout tropical oceans of the world (Waring et al. 2007). In the western North Atlantic, it generally occurs from North Carolina to the West Indies and down to the equator (Würsig et al. 2000), although there have been a few sightings at the southern edge of Georges Bank (Waring et al. 2007). 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). The best estimate for the population off the U.S. east coast is 4439 (Waring et al. 2007). Abundance estimates for this largely offshore species in the Northwest Atlantic are not available.

Pantropical spotted dolphins are usually pelagic, although they occur close to shore where water near the coast is deep (Jefferson et al. 2008). They extremely gregarious, forming schools usually numbering <100 for the coastal form and often in the thousands for the offshore form (Jefferson et al. 2008). These large aggregations contain smaller groups that can consist of only adult females with their young, only juveniles, or only adult males (Perrin and Hohn 1994). Baird et al. (2001) found that the coastal form of this species in Hawaii dove deeper at night (mean of 57 m, maximum 213 m) than during the day (mean of 13 m, maximum 122 m).

Sightings of pantropical spotted dolphins in the proposed study area are not expected.

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). 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). 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. 2007). The best estimate of abundance for the population off the U.S. east coast is 50,978 (Waring et al. 2007).

The Atlantic spotted dolphin can be seen in groups of up to 50 or more, but coastal groups usually consist of 5–15 (Jefferson et al. 2008). Davis et al. (1996) found that most dives of Atlantic spotted dolphins in the Gulf of Mexico were shallow and of short duration, regardless of the time of day. Spotted dolphins usually dove to depths of 4 to <30 m, and the deepest dives recorded were to 40–60 m. Most of the dives were less than 2 min in duration (Davis et al. 1996).

During summer, Atlantic spotted dolphins are sighted in shelf waters south of Chesapeake Bay, and near the continental shelf edge, on the slope, and offshore north of there (Waring et al. 2007). During fall, very few Atlantic spotted dolphins occur north of New Jersey (Fig. B-15a in DoN 2005).

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). There is no estimate for numbers of spinner dolphins off the U.S. east coast because it has been seen only rarely in surveys.

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). Spinner dolphins can be seen in groups of 30 to hundreds or even thousands (Würsig et al. 2000). They often travel in mixed-groups with pantropical spotted dolphins and other species (Perrin 2002).

The distribution of spinner dolphins in the Atlantic is poorly known, but they are thought to occur in deep waters along most of the U.S. coast; sightings off the northeast U.S. coast have occurred exclusively in offshore waters >2000 m (Waring et al. 2007). Thus, sightings of spinner dolphins in the proposed study area are not expected.

Striped dolphin (*Stenella attenuata*)

The striped dolphin has a cosmopolitan distribution in tropical to warm temperate waters (Perrin et al. 1994b). In the western North Atlantic, this species occurs from Nova Scotia to the Gulf of Mexico and south to Brazil (Würsig et al. 2000). The best abundance estimate for the striped dolphin off the U.S. east coast is 94,462 (Waring et al. 2007).

Striped dolphins are primarily pelagic, apparently preferring waters offshore from the continental shelf and typically over the continental slope in waters associated with upwelling or convergence zones (Au and Perryman 1985). Striped dolphin group sizes are typically several dozen to 500, though groups of thousands sometimes form (Jefferson et al. 2008). School composition varies and consists of adults, juveniles, or both adults and juveniles (Perrin et al. 1994b). Their breeding season has two peaks, one in the summer and one in the winter (Boyd et al. 1999). Striped dolphins are believed to be capable of diving to depths of 200–700 m based on stomach content analyses (Archer and Perrin 1999).

Off the northeastern U.S. coast, striped dolphins occur along the continental shelf edge and over the continental slope from Cape Hatteras to the southern edge of Georges Bank (Waring et al. 2007). In all seasons, striped dolphin sightings have been centered along the 1000-m depth contour, and sightings have been associated with the north edge of the Gulf Stream and warm core rings (Waring et al. 2007).

Short-beaked common dolphin (*Delphis delphis*)

The common dolphin is one of the most widely distributed cetaceans and occurs in temperate, tropical, and subtropical regions (Jefferson et al. 2008). There are two species of common dolphin: the long- and short-beaked common dolphins. However, the long-beaked common dolphin is much less abundant, and the short-beaked common dolphin is most likely the only species that would be encountered in the NWA. The best estimate of abundance for short-beaked common dolphins off the U.S. east coast is 120,743 (Waring et al. 2007).

Groups of short-beaked common dolphins can range from several dozen to over 10,000, and they are typically fast-moving with many aerial behaviors such as jumping and bow-riding (Jefferson et al. 2008). They can occupy a variety of habitats, but in the northeastern U.S., short-beaked common dolphins are most abundant within a broad band of waters 100–2000 m deep, paralleling the continental slope from 35ºN to the northeast edge of Georges Bank (Selzer and Payne 1988). They are also often associated with features of the Gulf Stream (Hamazaki 2002).

Short-beaked common dolphins occur from Cape Hatteras to Georges Bank during mid-January to May, move onto Georges Bank and the Scotian Shelf during mid-summer and fall, and have been observed in large aggregations on Georges Bank in fall (Selzer and Payne 1988; Waring et al. 2007). Mass strandings of common dolphins occurred on Massachusetts beaches from at least 2001 to 2006, including four separate events in 2005 (Waring et al. 2007).

White-beaked dolphin (*Lagenorhynchus albirostris*)

The white-beaked dolphin is widely distributed in cold temperature and subarctic North Atlantic waters (Reeves et al. 1999a), often occurring to the edge of the arctic pack ice (Carwardine 1995). It occurs in immediate offshore waters of the east coast of the North America, from Labrador to Massachusetts (Rice 1998). Off the northeastern U.S. coast, white-beaked dolphins are mainly found in the western Gulf of Maine and around Cape Cod (CETAP 1982 *in* Waring et al. 2007). The best estimate of abundance for white-beaked dolphins off the U.S. east coast is 2003 (Waring et al. 2007). Reeves et al. (1999a) estimated that there were ~high tens to low hundreds of thousands of white-beaked dolphins in the North Atlantic.

White-beaked dolphins are found widely over the continental shelf, especially along the shelf edge (Carwardine 1995). They usually occur in groups of <30, with occasional groups of several hundred or even thousands (Jefferson et al. 2008). While feeding, white-beaked dolphins are sometimes associated with large whales such as fin or humpback whales, but also with smaller cetaceans including pilot and killer whales, as well as bottlenose, white-sided, and common dolphins (Jefferson et al. 1993).

White-beaked dolphins have been observed in shallow, coastal waters near Cape Cod during Cetacean & Turtle Assessment Program (CETAP) surveys (Lien et al. 2001). In the 1970s, white-beaked dolphins were found primarily over the continental shelf of the Gulf of Maine and Georges Bank, but were apparently replaced by Atlantic white-sided dolphins as a result of shifts in prey species (Kenney et al. 1996). Mapping of historical records suggests that white-beaked dolphins occur primarily over the continental shelf north of Georges Bank in summer (DoN 2005).

Sightings of white-beaked dolphins in the proposed study area are not expected.

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), and concentrates in areas with high seafloor relief (Reeves et al. 2002). In the western North Atlantic it ranges from Labrador and southern Greenland to ~38ºN (Jefferson et al. 2008). The best abundance estimate for Atlantic white-sided dolphins off the U.S. east coast is 63,368 (Waring et al. 2007). Reeves et al. (1999b) estimated that there were ~tens to low hundreds of thousands white-sided dolphins in the North Atlantic.

Atlantic white-sided dolphins apparently replaced white-beaked dolphins on the continental shelf of the Gulf of Maine and Georges Bank, potentially as a result of increases in sandlance and declines in herring (Kenney et al. 1996). The Atlantic white-sided dolphin is gregarious; group size in New England waters is 2–2500 with a mean of 52.4 (Weinrich et al. 2001).

There are seasonal shifts in Atlantic white-sided dolphin distribution off the northeastern U.S. coast, with low numbers in winter from Georges Basin to Jeffrey's Ledge and very high numbers in spring in the Gulf of Maine. In summer, Atlantic white-sided dolphins are distributed northward from south of Cape Cod with the highest numbers from Cape Cod north to the lower Bay of Fundy, and in fall, the distribution is similar with lower numbers (Fig. B-21a *in* DoN 2005).

Risso's dolphin (*Grampus griseus*)

Risso's dolphin is primarily a tropical and temperate species distributed worldwide between 60ºN and 60ºS, where surface water temperatures are ~10ºC (Kruse et al. 1999). In the western Atlantic Ocean, this species is distributed from Newfoundland to Brazil (Kruse et al. 1999). The best abundance estimate for Risso's dolphin off the U.S. east coast is 20,479, including 15,053 from the northern U.S. Atlantic (Waring et al. 2007).

In the northern Gulf of Mexico, Risso's dolphin usually occurs over steeper sections of the upper continental slope (Baumgartner 1997) in waters 150–2000 m deep (Davis et al. 1998). In Monterey Bay, California, it is most numerous where there is steep bottom topography (Kruse et al. 1999). Risso's dolphin occurs individually or in small to moderate-sized groups of 10–100, although groups of up to 4000 have been reported (Jefferson et al. 2008). Dives have been recorded to a maximum depth of 600 m (DiGiovanni et al. 2005) with dive times up to 30 min (Jefferson et al. 2008).

Off the northeast U.S. coast during spring, summer, and autumn, Risso's dolphins are distributed along the continental shelf edge and occur from Cape Hatteras to Georges Bank, but they range around the MAB and into oceanic waters during the winter (Waring et al. 2007). Mapping of Risso's dolphin sightings off the U.S. east coast suggests that they could occur year-round from the Scotian Shelf to the coast of the southeastern U.S. in waters extending from the continental shelf to the continental rise (DoN 2005). The greatest occurrences of Risso's dolphins occur off New Jersey, near the continental slope, in fall (DoN 2005).

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). In the western Atlantic, it occurs from Maryland to Argentina (Rice 1998). The false killer whale is not included in the 2007 NMFS U.S. Atlantic Stock Assessment. Very few false killer whales were sighted off the U.S. northeast coast in the numerous surveys mapped by DON (2005).

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). False killer whales are gregarious and form strong social bonds, as is evident from their propensity to strand en masse (Baird 2002). They travel in groups of 20–100 (Baird 2002), although groups of several hundred are sometimes observed (Odell and McClune 1999). Recently-stranded groups ranged from 28 to over 1000 animals (Baird 2002).

Sightings of false killer whales in the proposed study area are not expected.

Killer whale (*Orcinus orca*)

The killer whale is cosmopolitan and globally fairly abundant; it has been observed in all oceans of the world (Ford 2002). 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). There is no population estimate for the killer whale off the U.S. east coast (Waring et al. 2007).

Killer whales appear to prefer coastal areas, but are also known to occur in deep water (Dahlheim and Heyning 1999). They are large and conspicuous, often traveling in close-knit matrilineal groups of a few to tens of individuals (Dahlheim and Heyning 1999). They have been reported to dive as deep as 264 m off British Columbia (Baird et al. 2005).

In the western North Atlantic, killer whales occur from the polar ice pack to Florida and the Gulf of Mexico (Würsig et al. 2000). Based on historical sightings and whaling records, killer whales apparently were most often found along the shelf break and offshore in the NWA (Katona et al. 1988). They are considered uncommon or rare in waters of the U.S. Atlantic EEZ; they only represented 0.1 % of all cetacean sightings (12 of 11,156 sightings) in surveys during 1978–1981 (CETAP 1982 *in* Waring et al. 2007). They are more common off New England in summer than in any other month, occurring nearshore and off the shelf break (Fig. B-24 *in* DoN 2005).

Long- and short-finned pilot whales (*Globicephala melas* and *G. macrorhynchus*)

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 and warm temperate waters (Olson and Reilly 2002). Their distributions apparently overlap. Water temperature appears to be the primary factor determining their distributions (Fullard et al. 2000). The two species are difficult to distinguish at sea, but their distributions are thought to have little overlap (Olson and Reilly 2002); off the mid-Atlantic U.S. coast is one of the locations where they do (Bernard and Reilly 1999). Because of the difficulty in distinguishing the two species, the best abundance estimate for both species off the U.S. east coast is 31,139 (Waring et al. 2007).

Pilot whales occur on the continental shelf break, in slope waters, and in areas of high topographic relief and have seasonal inshore/offshore movements coinciding with the abundance of their preferred prey, squid (Jefferson et al. 2008). Pilot whales are highly social, appear to live in stable female-based groups, and group sizes typically are 20–100, with some groups containing >1000 (Jefferson et al. 2008). Heide-Jørgensen et al. (2002) found that pilot whales outfitted with time-depth recorders dove to depths of up to 828 m, although most of their time was spent above depths of 7 m. Pilot whales are known to mass strand frequently (Olson and Reilly 2002). Pilot whales are often involved in relatively frequent mass strandings, and 2–168 pilot whales have stranded annually, either individually or in groups, along the eastern U.S. coast since at least 1980 (Waring et al. 2007).

In the NWA, pilot whales often occupy areas of high relief or submerged banks and associate with the Gulf Stream edge or thermal fronts along the continental shelf edge (Waring et al. 1992 *in* Waring et al. 2007). 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. During winter and early spring, long-finned pilot whales are distributed along the continental shelf edge off the northeast U.S. coast and in Cape Cod Bay, and in summer and fall also occur on Georges Bank, in the Gulf of Maine, and north into Canadian waters (Fig. B-25a in DoN 2005).

Harbor porpoise (*Phoecena phoecena*)

The harbor porpoise inhabits cool temperate to subarctic waters of the Northern Hemisphere (Jefferson et al. 2008). There could be 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. The harbor porpoise is not listed as endangered or threatened under the ESA, but the Gulf of Maine/Bay of Fundy stock is considered a strategic stock because average annual human-related mortality and serious injury exceeds potential biological removal (Waring et al. 2007). The best estimate of abundance for the Gulf of Maine/Bay of Fundy Stock is 89,054 (Waring et al. 2007). Jefferson et al. (2008) estimated a total of ~500,000 harbor porpoises in the North Atlantic.

Harbor porpoises tend to remain in relatively cool waters, seldom being found in waters warmer than 17ºC, presumably because these temperatures are preferred by their primary prey, Atlantic herring (Read 1999). They prefer areas with coastal fronts or topographically generated upwellings, and generally occur on the continental shelf, but also have an offshore component to their distribution (Westgate et al. 1998; Read 1999). They make short dives that are generally less than 5 min, spend 3–7% of their time at the surface versus 33–60% in the upper 2 m of the water column, and average dive depths range from 14–41 m (Westgate et al. 1995).

In the NWA, harbor porpoises concentrate in the northern Gulf of Maine and southern Bay of Fundy from July to September, with a few sightings ranging as far south as the northern edge of Georges Bank (Waring et al. 2007). From October-December and April-June, harbor porpoises are dispersed and range from New Jersey to Maine, although there are lower densities at the northern and southern extremes (Waring et al. 2007). Most animals would be found over the continental shelf, but some are also encountered over deep waters (Westgate et al. 1998). From January to March, they concentrate farther south, from New Jersey to North Carolina, with lower densities occurring from New York to New Brunswick (Waring et al. 2007). Because of their more northerly distribution in summer and early fall, sightings of harbor porpoises in the proposed study area are not expected.

(3) Pinnipeds

Harbor seal (*Phoca vitulina*)

Harbor seals are among the most widespread of pinnipeds, but they are primarily restricted to coastal regions (Jefferson et al. 2008). In the NWA, harbor seals are distributed from the eastern Canadian Arctic to southern New England and New York, with occasional occurrences in the Carolinas (Waring et al. 2007). Summing the estimates for several regions, the best abundance estimate for harbor seals off the U.S east coast is 99,340 (Waring et al. 2007).

Harbor seals occur in coastal waters and are rarely seen more than 20 km from shore; they often use bays, estuaries, and inlets, and sometimes follow anadromous prey upstream in coastal rivers (Baird 2001). They periodically haul out of the water; in New England, they typically haul out on rocky outcroppings and intertidal ledges (Schneider and Payne 1983; Payne and Selzer 1989). Most harbor seals haul out on land daily, although they can spend several days at sea feeding (Jefferson et al. 2008). Harbor seals can form large aggregations at haulout sites, sometimes co-existing with gray seals (Baird 2001). At sea, they are usually alone, but small groups occur and larger groups occur when prey is abundant (Jefferson et al. 2008). Over 50% of dives by harbor seals tagged in the Gulf of St. Lawrence were to depths <4 m, and the rest of the dives could be categorized into five types based on descriptive characteristics like dive depth, ascent and descent rates, and bottom time; the deepest dives average ~20 m (Lesage et al. 1999).

Harbor seals may occur year-round in the Gulf of Maine and New England waters (DoN 2005; Waring et al. 2007). From late September through late May, they occur predominantly south of Maine, with 75% of counted seals in New England waters hauling out on Cape Cod and Nantucket Island

(Schneider and Payne 1983; Payne and Selzer 1989). In summer, almost all harbor seals are found north of ~43º, in coastal waters of central and northern Maine and the Bay of Fundy (Fig. B-27a in DoN 2005).

Because of the more northerly distribution of harbor seals during summer, and their preference for coastal areas, few if any harbor seals are expected to be encountered during the proposed study.

Gray seal (*Halichoerus grypus*)

The gray seal is found in cold temperate to sub-arctic waters of the North Atlantic, and has three major populations, in eastern Canada, northwestern Europe, and the Baltic Sea (Jefferson et al. 2008). The western North Atlantic stock, considered as the same population as the eastern Canadian population, ranges from New England to Labrador (Lesage and Hammill 2001; Waring et al. 2007). Hammill (2005) estimated a total population of 52,500 gray seals for the NWA, including the Gulf of St. Lawrence and the Nova Scotia eastern shore.

The gray seal is primarily a coastal species, and foraging appears to be restricted to continental shelf regions (Lesage and Hammill 2001). Foraging gray seals tagged on Sable Island, Nova Scotia, nearly always remained within the 100-m isobath and mostly over offshore banks (Austin et al. 2006). There are two main breeding sites in the NWA where gray seals aggregate from December to February: Sable Island and in the southern Gulf of St. Lawrence. Gray seals disperse widely after breeding but return for a spring molt (Lesage and Hammill 2001).

After harbor seals, gray seals are the most commonly sighted seal in the northeastern U.S. (Waring et al. 2007). They range south along the east coast of the U.S., and strandings have occurred as far south as NC. Small numbers of gray seals were observed pupping on several isolated islands along the Maine coast and in Nantucket Sound in the mid-1980s (Katona et al. 1993). A year-round breeding population of ~400 animals on outer Cape Cod and Muskeget Island was documented in the late 1990s (Barlas 1999 *in* DoN 2005), and as many as 30 adult gray seals were reported at a haulout in New York waters (Hoover et al. 1999 *in* DoN 2005). Similar to harbor seals, grey seals are most common in the waters of Maine in winter and spring, and sighting records indicate that they occur only off northern Maine and in Canadian waters during summer and fall (Fig. 28a in DoN 2005). Thus, few if any gray seals are expected to occur in the proposed study at the time of the survey.

Harp seal (*Pagophilius groenlandicus*)

The harp seal has a widespread distribution in the Arctic and in cold waters of the North Atlantic (Jefferson et al. 2008). It is the most abundant seal in the North Atlantic, with most seals aggregating off the east coast of Newfoundland and Labrador to pup and breed; the remainder congregates in the Gulf of St. Lawrence (Lavigne and Kovacs 1988). DFO (2005) estimated a total of 5.9 million harp seals in these two areas; this is not considered a strategic stock by NMFS (Waring et al. 2007). This population estimate was updated to a total of 5.5 million in 2007 (DFO 2007).

Jefferson et al. (2008) indicate that vagrant harp seals reach as far south as New York. Sightings of harp seals off the U.S. east coast, from Maine to New Jersey, are rare but have been increasing in recent years, particularly from January to May (Harris et al. 2002; Harris and Gupta 2006; Waring et al. 2007). In fall, DoN (2005) predicted that harp seals may occasionally occur along the coast from southern Maine to Long Island. However, sightings of harp seals in the proposed study area are not expected.

Hooded seal (*Cystophora crisata*)

The hooded seal inhabits the Arctic and high latitudes of the North Atlantic, with four primary pupping areas, in the Gulf of St. Lawrence, northeast of Newfoundland, Davis Strait, and Greenland

(Jefferson et al. 2008). Pupping and breeding occurs on pack ice in March (Waring et al. 2007). A total of 592,100 hooded seals are estimated in the western North Atlantic (ICES 2006).

Hooded seals appear to prefer deeper water and occur farther offshore than harp seals (Lavigne and Kovacs 1988). Although they tend to occur at high latitudes of the North Atlantic, hooded seals are highly migratory and known to wander widely, with animals beached on the U.S. east coast from New England to Florida and Puerto Rico (Waring et al. 2007; Jefferson et al. 2008). Occurrences of hooded seals tend to be from January-May in New England waters and summer or fall off the southeast U.S. coast (McAlpine et al. 1999; Harris et al. 2002; Waring et al. 2007). Sightings of hooded seals in the proposed study area are not expected.

Seabirds

Only one seabird species of conservation concern, the roseate tern (*Sterna dougallii*), could occur in or near the proposed study area.

(1) Roseate Tern

The northeastern U.S. population of roseate tern is listed as ***Endangered*** under the ESA and by all states from Maine to New Jersey (Hoopes et al. 1994). Historically, the northeastern population suffered from plume harvesting for millinery, but it is currently threatened by encroachment on breeding habitat by growing gull populations and by predation from the Norway rat and red fox. The roseate tern breeds in coastal areas from Québec to Long Island, NY. About 80% of the northeastern population of 3775 pairs nests at Bird Island, MA, and Great Gull Island, NY (USFWS 1998 *in* Gochfeld et al. 1998). There have been recent, isolated instances of breeding in New Jersey and North Carolina (Gochfeld et al. 1998).

The roseate tern nests on rocky offshore islands, barrier beaches, and salt marsh islands close to shallow-water foraging sites with sandy bottoms, bars, or shoals (Hoopes et al. 1994). Breeding birds arrive at northeastern U.S. colonies from late April to mid-May (Cooper et al. 1970 *in* Gochfeld et al. 1998), whereas non-breeding sub-adults and first-time breeders arrive from mid-June to mid-July (J. Spendelow, pers. comm. *in* Gochfeld et al. 1998). At Bird Island, most eggs are laid from 20 May to 4 June (Burger et al. 1996 *in* Gochfeld et al. 1998). However, peak laying date can vary by as much as 20 days (Nisbet 1981, 1989, both *in* Gochfeld et al. 1998). Birds nesting at Bird Island feed primarily at three sandbars, but also at tide rips up to 30 km from the island (Heinemann 1992 *in* Gochfeld et al. 1998). However, there are no published data on mean distance.

Following breeding, many birds move northeastward in August and September before southward fall migration begins in mid-September. Color-banding has shown that birds from at least eight colonies in the northeastern U.S. are in southern Maine in August (peak numbers in mid-August), where they feed offshore and roost on rocky islands (Shealer and Kress 1994 *in* Gochfeld et al. 1998). Birds from these colonies re-aggregate at a small number of sites on outer Cape Cod in late September before southward migration (Trull et al. 1999). Although most individuals are found in coastal habitats, little is known about habitat preferences during migration or migration routes, except that migration takes place mainly offshore (Gochfeld et al. 1998). Small numbers of roseate terns are seen during autumn on coastal beaches between the breeding and wintering range along the coast of South America, but in spring few are seen in coastal areas between Trinidad and MA (Gochfeld et al. 1998). However, some occur far at sea during migration in May and August–October (Gochfeld et al. 1998, Read et al. 2009). Peak numbers are seen in early September (Lee 1995).

Roseate terns feed primarily on small, schooling, marine fish, which they forage for over shallow sandbars, shoals, inlets or schools of large, predatory fish such as tuna (Safina 1990a, 1990b; Heinemann

1992; Shealer and Burger 1993, 1995; all *in* Gochfeld et al. 1998). This species captures its prey by plunge-diving and may become completely immersed down to depths of at least 0.5 m for more than one second (Duffy 1986 *in* Gochfeld et al. 1998).

Sea Turtles

Two species of sea turtle, leatherback (*Dermochelys coriacea*) and loggerhead turtles (*Caretta caretta*), are common off the U.S. east coast. Kemp's ridley (*Lepidochelys kempii*) and green turtles (*Chelonia mydas*) also occur in this area at much lower densities. A fifth species, the hawksbill turtle (*Eretmochelys imbricata*), is considered very rare and possibly extralimital to the NWA (Lazell 1980; Eckert 1995a); it is not considered further.

(1) Leatherback Turtle (*Dermochelys coriacea*)

The leatherback turtle is listed as ***Endangered*** under the ESA (NMFS and USFWS 2007a), ***Critically Endangered*** on the 2008 IUCN Red List of Threatened Species (IUCN 2008), and in CITES Appendix I (UNEP-WCMC 2008). The most recent estimate of the worldwide population is 35,860 females (Spotila 2004). Globally, there have been sharp population declines of leatherback turtles, but these trends have been particularly dramatic in the Pacific Ocean (Spotila et al. 1996; 2000). Kenney (1996) estimated that several hundred individuals use the continental shelf waters of the northeast U.S.

The leatherback is the largest and most widely distributed sea turtle, ranging far from its tropical and subtropical breeding grounds. It has the most extensive range of any adult, 71ºN to 47ºS (Eckert 1995b). Leatherbacks are highly pelagic, spending the majority of their time in water >1000 m deep and possibly swimming more than 10,000 km in a year (Hays et al. 2006; Eckert 1998 *in* NMFS 2002). Female leatherbacks approach coastal waters only during the reproductive season (EuroTurtle 2008), whereas males are rarely observed near nesting sites (NMFS 2002).

This species is one of the deepest divers in the ocean, with dives deeper than 4000 m (Spotila 2004). The leatherback dives continually and spends short periods of time on the surface between dives (Eckert et al. 1986; Southwood et al. 1998). Off Playa Grande, Costa Rica, six inter-nesting female leatherbacks spent 57–68% of their time underwater, diving to a mean depth of 19 m for 7.4 min (Southwood et al. 1999 *in* NMFS 2002). Off St. Croix, six inter-nesting females dove to a mean depth of 61.6 m for an average of 9.9 min, and post-dive surfacing intervals averaged 4.9 min (Eckert et al. 1989). During shallow-water diving in the South China Sea, typical dive durations averaged 6.9–14.5 min, with a maximum of 42 min (Eckert et al. 1996). Off central California, leatherbacks dove to 20–30 m with a maximum of 92 m, corresponding to the vertical distribution of their prey, and mean dive and surface durations were 2.9 and 2.2 min, respectively (Harvey et al. 2006). During migrations or long distance movements, leatherbacks maximize swimming efficiency by traveling within 5 m of the surface (Eckert 2002).

In the northern Atlantic Ocean, leatherbacks nest during January–July in the Caribbean islands, Costa Rica, Panama, Columbia, Surinam, and French Guiana. The southeast coast of Florida supports minor nesting colonies (Spotila 2004). Hatchling leatherbacks are pelagic, but nothing is known about their distribution for the first four years (Musick and Limpus 1997). Post-nesting adult leatherbacks appear to migrate along bathymetric contours from 200 to 3500 m (Morreale et al. 1994). Leatherbacks are highly migratory, feeding in convergence zones and upwelling areas in the open ocean, along continental margins, and in archipelagic waters (Morreale et al. 1994; Eckert 1995b). There is evidence that leatherbacks are associated with oceanic front systems, such as shelf breaks and the edges of oceanic gyre systems where their prey is concentrated (Lutcavage 1996). Leatherbacks feed mainly on jellyfish, tunicates, and other epipelagic soft-bodied invertebrates (den Hartog and van Nierop 1984; Davenport and Balazs 1991).

In the northwestern Atlantic Ocean, leatherbacks are thought to follow the Gulf Stream because jellyfish, their main prey, are concentrated where this current meets the cold Labrador Current. It is not uncommon for leatherback turtles to migrate up the eastern U.S. coast and occur as far north as New England (Eckert 1995b), or even into Canadian waters off the Scotian Shelf or Newfoundland and Labrador (James et al. 2005). Leatherbacks are commonly taken incidentally in the longline fishery (Brady and Boreman 1994). Of 1264 leatherbacks captured off the east coast by the U.S. longline fleet during 1992–1995, 47% were in the northeast distant NMFS pelagic fishing area (outside of the proposed survey area). Off the U.S. east coast, virtually all leatherbacks captured were just offshore from the 200-m depth contour; 14% of the catch was in the northeastern coastal area north of Cape Cod (Witzell 1999). Most catches off the U.S. east coast were in summer and fall, with smaller numbers in spring and very few in winter (Witzell 1999).

Leatherback occurrence in New England waters has been documented for many years, with most historic records from March–August focused around the Gulf of Maine and Georges and Browns Banks; in fall, they were focused more southerly in New England bays and sounds (Lazell 1980). Leatherbacks tagged off Cape Breton and mainland Nova Scotia during summer remained off eastern Canada and the northeastern U.S. coast before most began migrating south in October (James et al. 2005). Some of these tags remained attached long enough to observe northward migrations, with animals leaving nesting grounds during February–March and typically arriving north of 38ºN during June, usually in areas within several hundred km of where they were observed in the previous year. Virtually all of the leatherback in sighting records off the northeastern U.S. were in summer and were off southern New Jersey, the southeastern tip of Long Island, and southern Nova Scotia (Fig. C-2a *in* DoN 2005).

(2) Loggerhead Turtle (*Caretta caretta*)

The loggerhead turtle is listed as ***Threatened*** throughout its range under the ESA, ***Endangered*** on the 2008 IUCN Red List of Threatened Species (IUCN 2008), and is listed in CITES Appendix I (UNEP-WCMC 2008). Spotila (2004) estimated the global population at 43,320-44,560 nesting females. Shoop and Kenney (1992) estimated that at least 8000–11,000 loggerheads occur in northeastern U.S. waters each summer.

Loggerhead turtles are found in temperate and tropical areas of the Atlantic, Pacific, and Indian Oceans, with the majority of nesting occurring along the western rims of the mid- and equatorial Atlantic and Indian Oceans (Spotila 2004). Migrating loggerhead turtles have been found to spend 89–96% of their time underwater, and loggerheads on feeding grounds spend ~85% of their time underwater (Byles 1988 *in* Lutcavage and Lutz 1997; Musick et al. 1994). In the North Pacific Ocean, two loggerheads tagged with satellite-linked depth recorders spent ~40% of their time in the top meter and almost all their time shallower than 100 m; 70% of the dives were no deeper than 5 m (Polovina et al. 2003). Post-nesting female loggerheads off Japan made routine dives to 9–22 m for 17–30 min, with maximum depths of 211–233 m (Sakamoto et al. 1990, 1993 *in* Lutcavage and Lutz 1997). Small juvenile loggerheads live at or near the surface; for the 6–12 years spent at sea as juveniles, they spend 75% of their time in the top 5 m of water (Spotila 2004). Juveniles spend more time on the surface in deep, offshore areas than in shallow, nearshore waters (Lutcavage and Lutz 1997). Ten juvenile pelagic-stage loggerheads tagged off Madeira Island generally made shallow dives, spending most of the time near the surface, and ~20% of their time was spent at 10–25 m. Occasionally, dives were deep for long periods; maximum depths for the 10 turtles were 86–196 m, and maximum times were 90–240 min (Dellinger and Freitas 2000).

Major nesting areas for loggerheads in the western North Atlantic are located in the southeastern U.S., principally southern Florida, but also as far north as the Carolinas and occasionally Virginia; the nesting season is from May to August (Spotila et al. 2004). Each female lays a mean of 3.5 clutches with an inter-nesting period of 12–16 days (Spotila 2004), so is at or near the nesting beach for ~50 days. Loggerheads nest every 2.5–3.7 years (NMFS and USFWS 2008). Post-nesting females typically make directed migrations away from the nesting beach that can be coastal or can involve crossing offshore pelagic regions to discrete foraging areas located on continental shelves; they show strong site fidelity to foraging areas (Schroeder et al. 2003). Most females tagged on North Carolina nesting beaches traveled north to forage at higher latitudes (primarily off New Jersey, Maryland, and Delaware) during the summer and south to wintering grounds off the southeastern U.S. in the fall (Hawkes et al. 2007). Movements were associated with the warm waters at the edge of the Gulf Stream in coastal waters typically <100 m (Hawkes et al. 2007). Some males may stay year-round in breeding grounds near nesting beaches (Plotkin 2003).

In the North Atlantic, post-hatchling loggerheads are known to migrate from their rookery beaches in the southeastern U.S. to oceanic development habitats in waters of the eastern North Atlantic (Frick et al. 2003). Once hatchlings make it to the oceanic environment, they are largely inactive and carried by currents; they associate with floating material and concentrate around downwelling lines over the continental slope that develop along the Gulf Stream front (Witherington 2002). They spend their first ~10 years (Bolten and Balazs 1995; Avens et al. 2003) inhabiting the North Atlantic Gyre, which extends roughly from Bermuda to the Azores. Such movements of pelagic-stage turtles are substantiated by recaptured tagged turtles (Bolten et al. 1994, 1996) and by incidental capture in longline fisheries around the Azores and Madeira (e.g., Brongersma 1995). Some post-hatchling loggerheads, likely originating from Florida's east coast, begin their pelagic stage in Atlantic waters west of the Gulf Stream (Witherington 1994).

After leaving their pelagic stage, loggerheads originating from the east coast of the U.S. return there to forage in inshore waters such as sounds, bays, and estuaries (Avens et al. 2003). Some demersal juveniles make seasonal foraging migrations into temperate latitudes as far north as Long Island, NY (Shoop and Kenney 1992 *in* Musick and Limpus 1997). Lazell (1980) reported that loggerheads were historically common in New England waters and the Gulf of Maine. Of 1337 loggerheads captured off the east coast by the U.S. longline fleet during 1992–1995, 70% were in the northeast distant NMFS pelagic fishing area (well outside of the proposed seismic survey area). Off the U.S. east coast, virtually all loggerheads captured were just offshore from the 200-m depth contour; 11% of the catch was in the northeastern coastal area north of Cape Cod (Witzell 1999). Most catches off the U.S. east coast were in summer and fall, with smaller numbers in spring and very few in winter (Witzell 1999). Murray (2008) analyzed sea turtle bycatch in bottom otter trawls at water depths <50 m in the U.S. MAB between 34ºN and ~41.5ºN during 1994–2004. Most (92%) of the 72 turtles caught were loggerheads, most (88%) of the loggerhead catch was between 34ºN and ~39ºN, most (58%) of the catch was during fall (October–December), and all but two turtles were caught in water depths >31 m, whereas ~60% of the trawl effort was in water depths >50 m. Recent studies indicate that some loggerhead turtles remain in U.S. mid-Atlantic waters during winter, hibernating in deep waters where food productivity remains high, with potentially large aggregations occurring in and around North Carolina, Virginia, and Florida (Hawkes et al. 2007). Sighting records of loggerheads off the northeastern U.S. were in all seasons in continental shelf and slope waters from Cape Cod to southern Florida, with greatest concentrations in mid-continental shelf waters off New Jersey during the summer (Fig. C-3a *in* DoN 2005). There are increased stranding records of loggerheads from Cape Cod Bay and Long Island Sound in the fall (DoN 2005); loggerheads may be unable to exit these inshore habitats which can result in hypothermia as temperatures drop in late fall (Burke et al. 1991 *in* DoN 2005).

(3) Kemp's ridley turtle (*Lepidochelys kempii*)

Kemp's ridley turtle is listed as ***Endangered*** under the ESA, ***Critically Endangered*** on the 2008 IUCN Red List of Threatened Species (IUCN 2008), and is listed in CITES Appendix 1 (UNEP-WCMC 2008). Spotila (2004) estimated the worldwide population at ~5000 nesting females.

Kemp's ridley turtles have a more restricted distribution than other sea turtles, with adults primarily located in the Gulf of Mexico and some juveniles also feeding along the U.S. east coast, including Chesapeake Bay, Delaware Bay, Long Island Sound, and waters off Cape Cod (Spotila 2004). They can dive to 50 m, with dives lasting 12–18 min and up to ~45 min (Spotila 2004). Nesting occurs primarily along the central and southern Gulf of Mexico coast during May–late July (Morreale et al. 2007). There have also been some rare records of females nesting on Atlantic beaches of Florida, North Carolina, and South Carolina (Plotkin 2003). After nesting, female Kemp's ridley turtles travel to foraging areas along the coast of the Gulf of Mexico, typically in waters <50 m deep from Mexico's Yucatan Peninsula to southern Florida; males tend to stay near nesting beaches in the central Gulf of Mexico year-round (Morreale et al. 2007). Only juvenile and immature Kemp's ridley turtles appear to move beyond the Gulf of Mexico into more northerly waters along the U.S. east coast.

Hatchlings are carried by the prevalent currents off the nesting beaches and do not reappear in the neritic zone until they are about two years old (Musick and Limpus 1997). Those juvenile and immature Kemp's ridley turtles that migrate northward past Cape Hatteras probably do so in April and return southward in November (Musick et al. 1994). North of Cape Hatteras, juvenile and immature Kemp's ridleys prefer shallow-water areas, particularly along North Carolina and in Chesapeake Bay, Long Island Sound, and Cape Cod Bay (Musick et al. 1994; Morreale et al. 1989; Danton and Prescott 1988; Frazier et al. 2007). There are historical summer sightings and strandings of Kemp's ridley turtles from Massachusetts into the Gulf of Maine (Lazell 1980). Occasionally, individuals can be carried by the Gulf Stream as far as northern Europe, although those individuals are considered lost to the breeding population. Virtually all sighting records of Kemp's ridley turtles off the northeastern U.S. were in summer off the coast of New Jersey (Fig. c-4a *in* DoN 2005).

(4) Green turtle (*Chelonia mydas*)

The green turtle is listed as ***Threatened*** under the U.S. ESA throughout its Atlantic range, except for the ***Endangered*** population nesting in Florida. It is listed as ***Endangered*** on the 2008 IUCN Red List of Threatened Species (IUCN 2008) and in CITES Appendix I (UNEP-WCWM 2008). The worldwide green turtle population, estimated at 88,520 nesting females, has declined 50–70% since 1900 (Spotila 2004).

The green turtle is widely distributed in tropical and subtropical waters near continental coasts and around islands, although they have been recorded 500–800 miles from shore in some regions (Eckert 1993 *in* NMFS 2002). Green turtles typically make shallow (20–50 m) dives (Lutcavage and Lutz 1997) although they have been observed as deep as 110 m in the Pacific Ocean (Berkson 1967 *in* Lutcavage and Lutz 1997). Green turtles spend most of their time feeding or resting underwater (Rice et al. 2000). Three subadult green turtles tagged in Hawaii spent averages of 9, 14, and 19 h/day foraging at depths <2 m, and 12, 10, and 5 h/day in resting dives at mean depths of 7–13 m (maximum depths were 16–40 m). Foraging dive durations were <10 min, and resting dive durations were 59, 44, and 24 min (Davis et al. 2000; Rice et al. 2000). Six green turtles tagged in the Gulf of California spent 6% of their time within 2 m of the surface, 39% of their time in resting dives to a mean of 10 m, and the remainder diving to depths up to ~50 m (Seminoff et al. 2005).

The most important nesting beaches in the northern Atlantic are in Costa Rica; the Yucatan Peninsula, Surinam, and eastern Florida south of Cape Canaveral, where they nest primarily between May and August (Thompson 1988; Spotila 2004). Females typically show nest-site fidelity, and nest repeatedly in the same spot, or at least on the same beach from which they hatched, laying 1–7 clutches over 12–14 days every 2–6 yr (Spotila 2004). Hatchlings are epipelagic (surface dwelling in the open sea) for ~1–3 or more years. Subsequently, they live in bays and along protected shorelines, feeding during the day on seagrass and algae (Bjorndal 1982), although it may be that some remain in the open ocean, never recruiting to coastal feeding areas (NMFS and USFWS 2007b). Juvenile and sub-adult green turtles may travel thousands of kilometers before they return to breeding and nesting grounds (Carr et al. 1978). The majority of green turtles found in U.S. waters are immature, with a carapace length of <60 cm (Thompson 1988).

Important feeding areas for green turtles in U.S. waters are primarily located in Florida and southern Texas, but Long Island Sound and inshore waters of North Carolina appear to be important to juveniles during summer months (NMFS and USFWS 2007b). Small numbers of juvenile green turtles have occurred historically in Long Island and Nantucket Sounds in New England (Lazell 1980). There are few sighting records, but DoN (2005) suggested that small numbers can be found from spring to fall as far north as Cape Cod Bay and in offshore waters of the southern edge of Georges Bank.

Fish Resources

In the MAB, fish species diversity decreases from south to north into the Gulf of Maine. Twice as many fish species occur in the MAB (~250 species) compared to northern areas (e.g., Gulf of Maine, Georges Bank). Seasonal temperature fluctuation is one of the primary factors influencing the distribution of fish species in these areas (Sherman et al. 1996; DoN 2005). Areas north of the proposed study area are dominated by temperate species, such as gadids (cod, haddock, and hake) and various species of flounder, which occur on a year-round basis (Azarovitz and Grosselein 1987 *in* DoN 2005). In contrast, fish species in the MAB are largely seasonal migrants with few temperate species (15%) and very few true residents (<5%) (Sherman et al 1996; DoN 2005). The majority of the MAB species are subtropical-tropical species (Froese and Pauly 2009), and many of them migrate into northern areas when water temperatures increase (Azarovitz and Grosselein 1987 *in* DoN 2005). The seasonal influx of southern fish into northern areas is most apparent in late summer or early fall when at least 33% of the species on Georges Bank and 20% of species in the Gulf of Maine are subtropical-tropical species (Azarovitz and Grosselein 1987 *in* DoN 2005).

Similar to the northeast continental shelf, Nantucket Sound supports a diverse fish community. Off the east coast of Cape Cod, a temperature gradient forms during the summer months, forming a boundary so that colder water fish occur to the north and warmer water fish occur to the south (Freeman and Walford 1974 *in* MMS 2009). The temperature gradient fluctuates north and south over an area of 32–64 km along the Cape Cod shoreline. Because of the temperature gradient along Cape Cod and its geographic location, Nantucket Sound serves as a migratory pathway for some warm-water species as they move into Cape Cod Bay and Massachusetts Bay. The Nantucket Sound area is also a northern border for some summer migrant species including black sea bass (*Centropristis striata*), scup (*Stenotomus chrysops*), and summer flounder (*Paralichthys dentatus*). In winter and early spring, some fish species are known to concentrate on shoal areas in Nantucket Sound for spawning or feeding, and some move from shoal areas to deeper water or channel areas. The winter flounder (*Pseudopleuronectes americanus*) is a species that is known to move from shoal areas to deeper water and channel areas in summer months, when shallower water in shoal areas has warmer water temperatures. In fall, when the water temperatures start to cool, the winter flounder moves back to shoal areas (MMS 2009).

The continental shelf waters of the northeast Atlantic states also support a variety of macroinvertebrates (e.g., molluscs and crustaceans) and highly migratory pelagic fishes (e.g., tunas, billfishes, swordfish, and sharks). The distribution of macroinvertebrates is largely influenced by the availability of benthic habitats (Theroux and Grosselein 1987 *in* DoN 2005), whereas the highly migratory species are often associated with thermal oceanic fronts (Block et al. 1998). The highly migratory species tend to undergo season-dependent inshore-offshore migrations by occupying warmer offshore waters in winter and inshore feeding and spawning areas during spring and summer (DoN 2005).

ESA-listed Species

Two ESA-listed fish species are known to occur in low densities the proposed study area; the Gulf of Maine segment of the Atlantic salmon (*Salmo salar*) and the shortnose sturgeon (*Acipenser brevirostrum*) are both listed as ***Endangered***.

(1) Atlantic salmon

Distributed from Greenland to Connecticut in the NWA, the Atlantic salmon is an anadromous species that exhibits an extremely complex life history involving use of both freshwater and marine habitats and extensive oceanic migrations (Kocik and Sheehan 2006). Atlantic salmon spawn in freshwater in the fall (Kocik and Sheehan 2006), typically from October through November, with a peak in late October (Scott and Scott 1988). The eggs remain in gravel substrates and hatch during winter, with fry emerging from the gravel in spring (Kocik and Sheehan 2006). Juvenile salmon, or parr, remain in freshwater one to three years in New England rivers, depending on growth and locality (Kocik and Sheehan 2006). When parr exceed 13 cm in length, they develop into smolts and migrate to the marine environment in spring. While at sea, movements can be extensive (Kocik and Sheehan 2006). Tagging studies on New England stocks have shown that salmon migrate as far north as Greenland (Kocik and Sheehan 2006).

Atlantic salmon may spend one or more years at sea. After the first winter at sea, ~10%, typically males, become sexually mature and return to natal rivers to spawn (Kocik and Sheehan 2006). Those remaining at sea feed in the coastal waters of West Greenland and Canada, typically off the coasts of Newfoundland and Labrador but as far south as Long Island Sound (Kocik and Sheehan 2006). Historically, these foraging areas were targeted by commercial Northeast Atlantic gillnet fisheries (Kocik and Sheehan 2006), which are now under moratoria. After their second winter at sea, most U.S. salmon return to freshwater systems to spawn (Kocik and Sheehan 2006), most notably in large cool rivers with extensive gravel-bottom headwaters, which are essential to early life stages (Scott and Scott 1988).

U.S. Atlantic salmon populations are delineated into four discrete Distinct Population Segments (DPSs) for the purposes of management (Kocik and Sheehan 2006). The DPSs listed by Kocik and Sheehan (2006) include the (1) Long Island Sound DPS, (2) Central New England DPS, (3) Gulf of Maine DPS and (4) Outer Bay of Fundy Salmon Fishing Area (SFA). The population of Atlantic salmon in the Gulf of Maine DPS represents the last wild population of U.S. Atlantic salmon and is listed under the ESA. At the time of listing under the ESA in 2000, there were at least eight rivers in the geographic range of the DPS known to still support Atlantic salmon populations. The Gulf of Maine DPS is part of a population in the North American Atlantic that historically ranged from northern Quebec southeast to Newfoundland and southwest to Long Island Sound (OPR 2009). During marine phases, Atlantic salmon may migrate into coastal waters as far south as Long Island. The Long Island Sound and Central New England DPSs were extirpated in the 1800s (Kocik and Sheehan 2006). The core populations of the Outer Bay of Fundy SFA have freshwater nursery areas in Canadian watersheds (Kocik and Sheehan 2006). Thus, the proposed study area represents only a small portion of the Atlantic salmon's marine range.

(2) Shortnose sturgeon

The shortnose sturgeon is a demersal, anadromous fish that is distributed along the east coast of North America from the St. John River, Canada, to the St. Johns River, FL (OPR 2009). NMFS recognizes 19 distinct population segments of shortnose sturgeon inhabiting 25 river systems over its distributional range (NMFS 1998b). Adjacent to the proposed study area, shortnose sturgeon population segments occur in the Merrimack River (MA), Connecticut River (MA/CT), Hudson River (NY), and Delaware River (NJ). Shortnose sturgeon prefer the nearshore marine, estuarine, and riverine habitat of large river systems (OPR 2009). Spawning generally occurs in the lower sections of rivers, with eggs deposited on hard bottom surfaces (Shepherd 2006). Juvenile sturgeon remain in freshwater for their first summer before migrating to estuaries in winter (Shepherd 2006). Migrations into marine waters rarely occur (NMFS 1998b). When in the marine environment, the shortnose sturgeon does not appear to make long-distance offshore movements (OPR 2009), so it likely does not occur in the proposed study area.

Shortnose sturgeon stock abundance steadily declined throughout the 20th century as a result of overfishing, pollution, and habitat destruction (NMFS 1998b; Shepherd 2006). The species was listed in 1967 as ***Endangered*** under the ESA (Shepherd 2006). In some systems, shortnose sturgeon abundance may be increasing to levels that would allow reconsideration of their endangered status (Shepherd 2006). Currently, significant numbers of shortnose sturgeon occur in the Hudson River (>38,000 individuals), Delaware River (~18,000 adults), and the Saint John River in New Brunswick, one of the largest in North America (NMFS 1998b; Shepherd 2006).

Commercial Species

The continental shelf waters off the U.S. east coast supports substantial finfish resources, including forage fish, groundfish, and highly migratory pelagic species. In addition, there are several invertebrate resources in the area. The fish and invertebrate resources support many active commercial and recreational fisheries. Table 4 summarizes the dominant species/groups in 2007 commercial landings of the four states (MA, RI, CT, and NY) adjacent to the proposed study area (NMFS 2009a). Nearly 71% of the overall catch weight landed (194,815 mt) consisted of pelagic species (Atlantic herring, *Clupea harengus harengus*; and Atlantic mackerel, *Scomber scombrus*), groundfish (skates; goosefish, *Lophius americanus*; Atlantic cod, *Gadus morhua*; and silver hake, *Merluccius bilinearis*), and invertebrates (Atlantic sea scallop, *Placopecten magellanicus*; longfin inshore squid, *Loligo pealeii*; ocean quahog clam, *Arctica islandica*; and American lobster, *Homarus americanus*). Species descriptions for the top ten commercial species landed in states adjacent to the proposed study area in 2007 are summarized below.

In Nantucket Sound, annual commercial finfish catches made by fishermen are dominated largely by squid, summer flounder, Atlantic mackerel, black sea bass, scup, bluefish (*Pomatomus saltatrix*), striped bass (*Morone saxatilis*), menhaden (*Brevoortia tyrannus*), butterfish (*Peprilus triacanthus*), winter flounder, king whiting (*Menticirrhus saxatilis*), and bonito (*Sarda sarda*). Important commercial shellfish include conch, ocean quahog, surf clam (*Spisula solidissima*), hard clam (=quahog; *Mercenaria*

TABLE 4. Top ten commercial fisheries species landed during 2007 in states adjacent to the proposed study area (NMFS 2009a).

Species/Group	Landing Weight (mt)	% of Total Landing Weight
Atlantic herring	36,621	18.8
Atlantic mackerel	22,972	11.8
Atlantic sea scallop	16,204	8.3
Skates	12,379	6.4
Longfin inshore squid	10,890	5.6
Ocean quahog clam	9,144	4.7
American lobster	8,676	4.5
Goosefish	8,494	4.4
Atlantic cod	6,532	3.4
Silver hake	5,808	3.0

mercenaria), horseshoe crab (*Limulus polyphemus*), and lobster (MMS 2009). From 1998 to 2007, an average of ~346 mt of commercial finfish and ~252 mt of commercial shellfish catches were harvested from Nantucket Sound, according to federal vessel trip reports (VTR; mandatory reports made by commercial fishermen to NMFS). Based on Massachusetts Division of Marine Fisheries (MassDMF) data for 1998–2007, an average of ~522 mt of commercial finfish (including squid) and ~750 mt of commercial shellfish catches were harvested in the sound (MMS 2009).

Fish stocks in federal waters are managed by regional fishery management councils (FMCs) established by the Magnuson-Stevens Fishery Conservation and Management Act (16 U.S.C. §1801-1882). Each FMC is mandated to develop fishery management plans (FMPs) to manage exploited fish and invertebrate species responsibly in U.S. federal waters. The proposed study area is located in waters under the jurisdiction of two FMCs: the New England FMC (NEFMC; Maine to Connecticut) and the Mid-Atlantic FMC (MAFMC; New York to NC). FMPs developed by NEFMC include Northeast Multispecies (groundfish), Scallop, Goosefish, Herring, Small Mesh Multispecies, Dogfish, Red Crab, Skate, and Atlantic Salmon (NEFMC 2009). The Atlantic Salmon FMP consists of a single provision that prohibits the possession of this species and any directed or incidental (bycatch) commercial fishery in federal waters (NEFMC 2009). The MAFMC has developed seven FMPs: Atlantic Mackerel-Squid-Butterfish, Bluefish, Spiny Dogfish, Summer Flounder-Scup-Black Sea Bass, Surf Clam-Ocean Quahog, Tilefish, and Monkfish (MAFMC 2009). The two FMCs jointly manage the monkfish and dogfish fisheries (MAFMC 2009; NEFMC 2009). NMFS participates in fishery management efforts by providing fisheries data and analysis and by managing highly migratory fishery species, including over 80 species of sharks, tunas, and billfishes (DoN 2005). The federal FMCs also work in conjunction with the Atlantic States Marine Fisheries Commission (ASMFC). The ASMFC coordinates the management and conservation of 22 Atlantic coastal fish species/groups (ASMFC 2009). State agencies, such as the MassDMF, are also responsible for the protection and enhancement of marine fishery resources and for the promotion and regulation of commercial and recreational fishing (MMS 2009).

Species Descriptions

Atlantic herring.—The Atlantic herring is distributed from southwestern Greenland and Labrador south to South Carolina. It schools in coastal waters, feeding on small planktonic copepods as young-of-the-year and mainly on copepods thereafter. Atlantic herring are facultative zooplanktivorous filter feeders that can switch to filter feeding when food densities and particle sizes are appropriate. Deeper waters are occupied during the day, whereas surface waters are frequented at night (Froese and Pauly 2009). Spawning generally occurs at depths of 20–90 m over rocks, shells, pebbles, gravel, and clay substrates (Reid et al. 1999). Spawning events typically occur from July to November in shallow waters, and known spawning locations include Nantucket Shoals and Georges Bank (Reid et al 1999).

The species is managed by the NEFMC under the Atlantic Herring FMP (NEFMC 2009). Herring are currently harvested with purse seine gear and, to a lesser extent, mid-water nets. The fishery occurs year-round with primary harvest locations changing with season. In winter (December–March), fishing primarily occurs in coastal waters off southern New England. During spring and summer, fishing activity shifts to the offshore waters of the Gulf of Maine. The inshore coastal waters off Maine, New Hampshire, and Massachusetts are largely targeted during fall (DoN 2005).

Atlantic mackerel.—The Atlantic mackerel is a pelagic schooling fish that is extremely active and highly migratory. The fishery is managed by the MAFMC under the Atlantic Mackerel-Squid-Butterfish FMP (MAFMC 2009). During winter, Atlantic mackerel occupy moderately deep water, 70–200 m, from Sable Island Bank to off Chesapeake Bay, typically in water temperatures >7ºC (Sette 1950 *in* Scott and Scott 1988). The overwintering aggregation undergoes a general inshore and northeastern migration in the spring. Approximately half of the overwintering aggregation moves towards U.S. coastal waters, while the other half moves northeastward to spawning grounds in the Gulf of St. Lawrence. The two groups are considered to be separate populations. Mackerel largely spawn in two separate regions in the northwest Atlantic: (1) in coastal waters between Cape Cod and Cape Hatteras, and (2) in the Gulf of St. Lawrence (Scott and Scott 1988). Spawning generally occurs from April to July in U.S. waters (Collette 2002).

Atlantic sea scallop.—The Atlantic sea scallop is a bivalve mollusc that inhabits the continental shelf from the north shore of the Gulf of St. Lawrence south to Cape Hatteras. Adults are generally found on coarse substrate, usually gravel, shells, and rock, in areas with some water movement, which is critical for feeding, oxygen, and waste removal. They are typically found at depths ranging from 18 to 110 m, but northern populations tend to be found in shallower water (Packer et al. 1999a).

The timing of spawning can vary with latitude, starting in summer in southern areas and in fall in northern areas. A major annual spawning period occurs in late summer–fall (August–October), although spring or early summer (June–July) spawning also occurs at specific locations. Scallop beds generally spawn synchronously in a short time, going from completely ripe to completely spent in less than a week. Spawning may be triggered by a number of factors, including rapid temperature change, presence in the water of sperm from other scallops, agitation, or tides (Packer et al. 1999a). Spawning occurs off Georges Bank in late September and early October (MacKenzie et al. 1978 *in* DoN 2005).

Atlantic sea scallops are managed under NEFMC's Sea Scallop Management Plan (NEFMC 2009). The species is managed as a single unit throughout its range in U.S. waters, with five stock components recognized: eastern Georges Bank, the Great South Channel, the Gulf of Maine, the New York Bight, and the waters adjacent to Delaware, Maryland, and Virginia. Scallops are harvested primarily through the use of scallop dredges and trawls (NEFMC 2009). Scallop harvesting with dredges apparently is not carried out in the study area, but there can be harvesting with bottom trawls (DoN 2005).

Skates.—Seven species of skates are listed in the northeast skate complex by NEFMC, including winter skate (*Leucoraja ocellata*), barndoor skate (*Dipturus laevis*), thorny skate (*Amblyraja radiate*), smooth skate (*Malacoraja senta*), little skate (*L. erinacea*), clearnose skate (*Raja eglanteria*), and rosette skate (*L. garmani*). The northeast skate complex is distributed along the coast of the northeast U.S. from the intertidal zone to depths >700 m (NEFMC 2009).

Skates are harvested in two different fisheries: (1) a fishery that supplies lobster harvesters with skates to use as bait for traps, and (2) a wing (fin) fishery that supplies skate meat for human consumption (NEFMC 2009). Skate landings occur year-round with a peak during summer. The bait fishery largely uses bottom trawls to target skates in federal waters <140 km off Rhode Island. Landings for the wing fishery mainly result from the by-catch in gear types associated with the groundfish, goosefish, and scallop fisheries. Some sink gillnets are used to target skates during the goosefish fishery (DoN 2005).

Longfin Inshore Squid.—The longfin inshore squid is a schooling cephalopod distributed in continental shelf and slope waters from Newfoundland to the Gulf of Venezuela. It occurs in commercial abundance from southern Georges Bank to Cape Hatteras (Jacobson 2005). Seasonal migrations are related to bottom water temperatures. The longfin inshore squid moves offshore during late autumn to overwinter along the edge of the continental shelf and returns inshore during spring and early summer (Jacobson 2005).

Longfin inshore squid spawn year-round with seasonal and geographical peaks that vary temporally and spatially. Most eggs are spawned from late spring to early summer in the Mid-Atlantic region (Jacobson 2005). Around Woods Hole, MA, north of the proposed study area, spawning begins from late April to May (Lange 1982 *in* DoN 2005). Spawning grounds along the Atlantic coast of North America appear restricted to coastal waters and embayments, such as Narragansett and Delaware bays (Jacobson 2005).

The population of longfin inshore squid from southern Georges Bank to Cape Hatteras is managed by the MAFMC under the Atlantic Mackerel-Squid-Butterfish FMP (MAFMC 2009). The domestic fishery, described by Hendrickson and Jacobson (2006), occurs primarily in southern New England and mid-Atlantic waters, with some fishing also occurring along the edge of Georges Bank. Fishing patterns generally reflect seasonal longfin inshore squid distribution patterns, and effort is generally directed offshore during October–April and inshore during May–September. The fishery is dominated by small-mesh otter trawlers, but nearshore pound-net and fish-trap fisheries occur during spring and summer. According to McKiernan and Pierce (1995) *in* MMS (2009), nearly all of the squid taken in Massachusetts waters are from Martha's Vineyard Sound and Nantucket Sound.

Ocean quahog.—The ocean quahog is a bivalve mollusk found in temperate and boreal waters on both sides of the North Atlantic. In the western Atlantic, ocean quahogs are distributed on the continental shelf from Newfoundland to Cape Hatteras. Adults are usually found in dense beds over level bottoms, just below the surface of the sediment, which ranges from medium- to fine-grained sand. Pelagic larvae can be found throughout the water column, and benthic juveniles are found offshore in sandy substrates (Cargnelli et al. 1999a).

Spawning is protracted, lasting from spring to fall and sometimes into January (Cargnelli et al 1999a) with peak spawning starting in August and ending by October (Serchuk et al. 1982). Multiple annual spawning events may occur at the individual and population levels.

The ocean quahog is managed under the Surf Clam-Ocean Quahog FMP of the MAFMC (MAFMC 2009). Clams are harvested mainly with hydraulic clam dredges in the MAB region. The fishery is active year-round with most vessels operating during the summer months (DoN 2005).

American lobster.—The American lobster is distributed in the NWA from Labrador to Cape Hatteras, from coastal waters out to depths of 700 m. Coastal lobsters are concentrated in rocky areas where shelter is available, and occasionally in high densities in mud substrates. Offshore populations are most abundant along the continental shelf edge in the vicinity of marine canyons. Lobsters exhibit a complex life cycle in which mating occurs following molting of the female. The extruded eggs are carried under the female's abdomen during a 9–11 month incubation period. The eggs hatch during late spring or early summer and the pelagic larvae undergo four molts before resembling adults and settling to the bottom. Approximately 20 molts over a course of 5–8 years occur before reaching minimum legal harvest size (Idoine 2006).

The American lobster fishery occurs in inshore and offshore waters, primarily using traps (i.e., lobster pots) and, to a lesser extent, bottom trawls. The offshore trap-fishing grounds include continental shelf areas from Massachusetts to New Jersey and along the shelf break from Lydonia Canyon to Norfolk Canyon. The majority of lobsters (80%) are harvested in nearshore areas. Lobster fishing occurs year-round both offshore and inshore, with peak fishing occurring during May–December (DoN 2005).

Goosefish.—The demersal goosefish or monkfish is a relatively warm-water anglerfish that ranges from Quebec to northeastern Florida, but is generally uncommon in nearshore waters south of North Carolina (Scott and Scott 1998; Froese and Pauly 2009). Adult goosefish favor open, sandy bottoms, and spend the majority of their time resting on the bottom, often in a depression or partially covered in sediment (Steimle et al. 1999a).

Overall, goosefish spawning occurs from spring through early fall with a peak in May–June. Spawning times vary depending on region (Steimle et al. 1999a), with southern populations spawning earlier (early spring off the Carolinas) than northern populations (May-June in the Gulf of Maine; into September in Canadian waters). Spawning locations are not well known, but are believed to extend from inshore shoals to offshore (Connolly 1920 *in* Steimle et al. 1999; Scott and Scott 1988)

An unusual aspect of the goosefish life history is that females produce relatively large (1.6–1.8 mm) eggs that are shed within buoyant, ribbon-like, non-adhesive, mucoid veils or rafts that may be 6–12 m long, 0.15–1.5 m wide, and >5 kg in mass. The egg veils float freely at the surface and are subject to the actions of wind, currents, and waves (Connolly 1920 *in* Steimle et al. 1999a). Hatch timing is temperature dependent and ranges from 6–7 days at 15ºC to ~100 days at 5ºC (Scott and Scott 1988). Goosefish live in the water column during the egg and larval stages and shift to a benthic existence during their juvenile and adult stages (Steimle et al. 1999a).

The fishery is currently managed under the Monkfish FMP by NEFMC and MAFMC (NEFMC 2009) with two stocks recognized: (1) a northern stock found in the Gulf of Maine and northern Georges Bank, and (2) a southern stock that ranges from southern Georges Bank to Cape Hatteras (Almeida et al. 1995; Richards 2000). The primary gear types used to catch goosefish are bottom trawls, sink gillnets, and scallop dredges. Goosefish landings occur over a wide area, including southern New England, and occur year-round. The trawl fishery targets goosefish in the canyons and on steep edges of the continental shelf break in the northern portion of the MAB. The targeted dredge fishery largely lands goosefish in Massachusetts (DoN 2005).

Atlantic cod.—Ranging from Greenland to Cape Hatteras in the northeast Atlantic, the Atlantic cod is a demersal, temperate species that occupies waters 10–600 m deep (Scott and Scott 1988). In the proposed study area, cod are non-migratory and only undertake minor seasonal temperature-dependent movements (Cohen et al. 1990). Spawning occurs at night on Georges Bank, in the Gulf of Maine, and over the inner half of the continental shelf off southern New England. Spawning normally occurs from November to April in depths <50 m (Cohen et al. 1990; Fahay et al. 1999a).

In U.S. waters, the Atlantic cod is managed under the Northeast Multispecies FMP as two separate stocks occurring in the Georges Bank and Gulf of Maine areas (NEFMC 2009). The Atlantic cod was once the primary target species in the offshore groundfish fishery; however, this fishery now includes 13 other benthic species/groups, including flounder and silver hake. The primary gear types used in this fishery are bottom trawls, sink gillnets, and bottom longlines. Fishing effort varies spatially and temporally in this fishery; fishing activities with the primary gear types occur throughout most the study area, except for a year-round fishing closure area, where bottom trawls, sink gillnets, and bottom longlines are prohibited, which extends into the eastern portion of the study area. The closure area does not exclude activity with other fishing gear, such as scallop dredges, pelagic (drift) gillnets, purse seines, pots and traps, shrimp trawls, mid-water trawls, and others (DoN 2005).

Silver hake.—The benthic silver hake or whiting occurs in waters from Newfoundland to North Carolina (Klein-MacPhee 2002) at depths of 55 to >900 m (Froese and Pauly 2009). During periods of feeding and spawning, the species is often found in dense schools. Nocturnal hunters, silver hake can be found throughout the entire water column in pursuit of prey. They are believed to rest on the bottom during the day (Klein-MacPhee 2002).

Spawning occurs year-round with peaks typically occurring between May and August (Klein-MacPhee 2002; Col and Traver 2006). Spawning occurs in continental shelf waters, particularly in areas along the southeastern and southern slopes of Georges Bank, around Nantucket Shoals, and south of MV to Cape Hatteras (Klein-MacPhee 2002). Shallow areas are occupied by silver hake in spring, with spawning occurring during late spring and early summer. The species migrates to deeper waters of the outer continental shelf and slope in autumn (Col and Traver 2006).

The silver hake is currently managed as two stocks in U.S. coastal waters: a northern stock in the Gulf of Maine and northern Georges Bank, and a southern stock extending from southern Georges Bank to the MAB (Col and Traver 2006). Both stocks are managed under NEFMC's "small mesh multi-species" program of the Northeast Multispecies FMP (NEFMC 2009).

Fishing Gear

A wide variety of fixed and mobile fishing gear is used to harvest commercial species in or near the study area (Table 5). The most common fixed-gear types include pots and traps, gillnets, and longlines. Trawls, purse seines, and dredges are commonly used mobile gear types. In Nantucket Sound, a variety of gear, including otter trawls, dredges, fish weirs, seines, traps and pots, and hand lines, is used to harvest commercial finfish and shellfish species. Commercial fishers with federal permits largely use otter trawls (to target squid and groundfish), fish weirs, and fish pots, according to VTR data for 1994–2007. MassDMF data for 1998–2007 indicated that commercial fishermen with state permits predominately use fish weirs and fish pots for finfish species. Conch pots and clam dredges were the dominant gear types used in commercial shellfish fisheries (MMS 2009).

Recreational Species

Recreational fisheries in the NWA can be divided into inshore and offshore components. The inshore recreational fishery involves rod-and-reel fishing from boats, beaches, marshes, docks, and piers. Larger boats, including charters and party boats, are used for offshore fishing. From Massachusetts to New Jersey, recreational fishing trips generally peak in the summer months and are lowest during the winter (DoN 2005). The number of participants in the recreational fishery can be substantial and varies annually. In 2007, preliminary estimates indicate that ~4.7 million recreational fishing trips, involving 1.3 million individuals from Massachusetts and other areas, targeted game fish in Massachusetts waters. The majority of fishing trips (>3.6 million) occurred in inland saltwater and brackish water bodies, such as bays, estuaries, and sounds. Nearly 720,000 trips occurred within 5.5 km of shore (excluding inland waters), and ~373,000 trips extended into federal waters more than 5.5 km from shore (NMFS 2009b).

Recreational fishers commonly fish in areas with characteristics that attract aggregations of game fish. These "hotspots" tend to have structural habitats, such as shoals, rocks, and reefs (natural and artificial). Hydrographic features, such as currents and nutrient-rich waters, also tend to concentrate fishes and fishermen (DoN 2005). Hotspots may occur from coastal areas to beyond the shelf break within the proposed study area.

TABLE 5. Types of gear and level of gear-specific fishing used within and near the proposed study area (adapted from DoN 2005).

Gear Type	Fishery	Project Area Fishing Effort
Trawls (bottom)	Multispecies/groundfish, skate, goosefish, spiny dogfish, clam, Atlantic sea scallop, American lobster, northern shrimp, winter trawl, mackerel, squid, bluefish	High level of fishing effort from coastal waters to shelf break (except year-round fishing closure area)
Trawls (mid-water)	Atlantic herring, winter trawl flynet	Very low effort in coastal waters on southern MV
Dredge (clam)	Ocean quahog, Atlantic surf clam, goosefish	Low- to high-effort level in mid-shelf waters
Dredge (scallop)	Atlantic sea scallop	None
Pots and Traps	American lobster, deep-sea red crab, black seabass	Low level of effort from coastal waters to shelf break
Purse Seines	Atlantic herring, tuna	Moderate level of effort
Gillnets (Sink)	Multispecies/groundfish, skate, goosefish, spiny dogfish, highly migratory species, mackerel, bluefish	High level of effort in predominately coastal waters
Bottom Longline	Multispecies/groundfish, spiny dogfish, highly migratory species, tilefish	Low level of effort near shelf break

A large portion of the recreational catch in federal waters (5.5–370 km from shore) of the northeast Atlantic states consists of bluefish (*Pomatomus saltatrix*), Atlantic mackerel, and cod. Other species caught by anglers include pollock (*Pollachius virens*), haddock (*Melanogrammus aeglefinus*), Atlantic halibut (*Hippoglossus hippoglossus*), hake, bluefin tuna (*Thunnus thynnus*), and swordfish (*Xiphias gladius*). Cod, pollock, flounder, and hake are mostly caught by boats fishing in federal waters. In federal waters off Massachusetts, gadids (Atlantic cod and other cods and hakes), striped bass, pollock, and Atlantic mackerel were the species predominately caught by recreational fishers in 2007 (NMFS 2009b; Table 6). Approximately 21% of the ~6100 mt of fish harvested during the 2007 Massachusetts recreational fisheries occurred in federal waters. The remaining 79% of catches occurred in state waters, largely concentrated in inland waterbodies. Striped bass and bluefish dominated recreational catches in Massachusetts state waters, followed by scup, gadids, and summer flounder (NMFS 2009b; Table 6). In addition, Atlantic mackerel and tautog (*Tautoga onitis*) were prominent catches in inland waters (NMFS 2009b; Table 6).

In Nantucket Sound, the leading recreational species include bluefish, scup, striped bass, fluke, black sea bass, little tunny (*Euthynnus alletteratus*), bonito, and tautog. The highest recreational fishing pressure in Nantucket Sound occurs from June until September, when tourists are vacationing in this region. During 2005–2007, the average annual total recreational fishing effort in Nantucket Sound was estimated at 635,047 trips with a peak during July and August (272,655 trips). The trips consisted predominately of shore-based fishing followed by private/rental boat fishing and party/charter boat fishing. The private/rental boat fishing is the most important mode of recreational fishing in Nantucket Sound (MMS 2009).

Sharks are also targeted recreationally with rod and reel in inshore and offshore waters. Most sharks are caught from small- to medium-sized boats, whereas large sharks (e.g., great white, *Carcharodon carcharias* and mako, *Isurus oxyrinchus*) are harvested using larger ocean-going vessels. Charter boats hired out for shark fishing are mostly active from May to September. Other large pelagics, such as bluefin tuna, swordfish, and billfishes (e.g., marlins and sailfish) are big game fish on the Atlantic

TABLE 6. 2007 Massachusetts recreational fisheries species and catch weights (from NMFS 2009b).

Inland Waters (bays, estuaries)		State Waters		Federal Waters	
Species	Weight (kg)[1]	Species	Weight (kg)[1]	Species	Weight (kg)[1]
Striped bass	1,572,614	Striped bass	362,995	Other cods/hakes	411,252
Bluefish	797,076	Bluefish	339,912	Atlantic cod	368,030
Atlantic mackerel	467,931	Scup	73,682	Striped bass	234,828
Atlantic cod	236,369	Other cods/hakes	56,816	Pollock	114,426
Scup	211,800	Atlantic cod	33,655	Atlantic mackerel	88,784
Tautog	153,304	Summer flounder	25,006	Bluefish	46,075
Other cods & hakes	99,270	Black sea bass	19,352	Other fishes	13,089
Black sea bass	66,997	Cunner	15,756	Summer flounder	2,979
Summer flounder	65,901	Atlantic mackerel	4,638	Dolphinfish	1,935
Other tuna/mackerel	63,062	Winter flounder	3,417	Winter flounder	154
Other fishes[2]	138,540			Herrings	21
Total	3,872,864	Total	935,229	Total	1,281,573

[1] Catch weights are minimum values for (1) fish brought back to the dock and identified by a trained individual, and (2) fish that are used for bait, released dead, or filleted (i.e., fish are killed and identified by individual anglers). Catch weights do not include fish that were caught and released alive.

[2] Includes “other fishes” (60,924 kg), little tunny/Atlantic bonito (22,529 kg), cunner (19,393 kg), winter flounder (15,193 kg), herrings (11,838 kg), dogfish sharks (5939 kg), triggerfish/filefish (2673 kg), skates/rays (43 kg), and sculpins (8 kg).

coast. The recreational fishery for billfishes largely occurs off Massachusetts and southward, mostly in summer months (DoN 2005).

Organized fishing tournaments are popular along the U.S. Atlantic coast and can involve a large number of participants targeting a variety of fish species. Each tournament generally has its own set of rules regarding time limits and geographical boundaries. The typical distance traveled by offshore tournament participants is ~140 km from the tournament host site. The number of tournaments and participants is dynamic and can vary annually (DoN 2005). Some examples of organized fishing tournaments on MV include the Oak Bluffs Monster Shark Tournament (mid-July), Oak Bluffs Top Gun Marlin and Tuna Tournament (late July, early August), and the MV Striped Bass and Bluefish Derby (mid-September to mid-October).

Essential Fish Habitat (EFH)

Areas designated as EFH contain habitat that is essential to the long-term survival and health of U.S. fisheries. Such habitat can include both water and substrate, and their respective chemical (e.g., water salinity, nutrients) and physical (e.g., water temperature, substrate type) properties. EFH does not include any biological component such as prey species. EFH includes those habitats that support the various life stages of each managed species. Therefore, a single species may require different EFH for breeding, spawning, nursery, feeding, and protection functions (NMFS 2008c). The entire eastern seaboard from the coast to the limits of the EEZ is EFH for one or more species or life stage for which EFH has been designated.

Essential Fish Habitat (EFH) is identified for only those species managed under a federal FMP established by Regional FMCs. Forty-nine species, consisting of groundfish, pelagic forage fish, highly migratory pelagics, cartilaginous fish, and invertebrates, have EFH designated for at least one life stage within the proposed study area; 19 species have EFH in Nantucket Sound (Tables 7, 8, and 9).

Habitats of Particular Concern (HAPC)

“Some observers have questioned the breadth of the mosaic of EFH designations for all federally managed species, and have suggested that [habitat areas of particular concern] HAPCs are the areas that

TABLE 7. Groundfish, pelagics, and invertebrates with Essential Fish Habitat (EFH) in the proposed study area. Species and stages with EFH in Nantucket Sound are shaded in gray. E = egg; L = larvae; J = juvenile; A = adult; SA = spawning adult. * = information currently unavailable; X = EFH present.

Species	E	L	J	A	SA	Source
American plaice	*	X	*	*	*	NEFMC 1998; Johnson et al. 1999a
Atlantic cod	X	X	X	X	X	Fahay et al. 1999a; MMS 2009
Atlantic halibut	*	*	*	*	*	Cargnelli et al. 1999c
Atlantic herring	X	X	X	X	X	Reid et al. 1999
Atlantic mackerel	X	X	*	X	*	Studholme et al. 1999; MMS 2009
Atlantic surfclam	*	*	X	X	*	Cargenelli et al. 1999d; MMS 2009
Barndoor skate	*	*	X	X	*	Packer et al. 2003a
Black sea bass	*	*	X	X	*	Steimle et al. 1999b
Bluefish	*	*	X	X	*	Fahay et al. 1999b
Butterfish	X	X	X	X	*	MAFMC 1998b; Cross et al. 1999; MMS 2009
Clearnose skate	*	*	*	*	*	NEFMC 2003; Packer et al. 2003b
Cobia	X	X	X	X	X	SAFMC 1998; MMS 2009
Goosefish	X	X	X	X	X	NEFMC 1998; Steimle et al. 1999a
Haddock	X	X	*	X	X	NEFMC 1998; Cargnelli et al. 1999e
King mackerel	X	X	X	X	X	SAFMC 1998; MMS 2009
Little skate	X	*	X	X	*	NEFMC 2003; Packer et al. 2003c; MMS 2009
Longfin inshore squid	*	*	X	X	*	MAFMC 1998b; Cagnelli et al. 1999b; MMS 2009
Northern shortfin squid	*	*	X	X	*	MAFMC 1998b; Cargnelli et al. 1999f; Jacobson 2005; MMS 2009
Ocean pout	X	X	X	X	*	NEFMC 1998; Steimle et al. 1999c
Ocean quahog	*	*	X	X	*	MAFMC 1998a; Cargnelli et al. 1999a
Offshore hake	X	X	X	X	X	NEFMC 1999; Chang et al. 1999a
Pollock	*	*	*	X	X	NEFMC 1998; Cargnelli et al. 1999g
Red deepsea crab	*	*	*	*	*	Steimle et al. 2001; NEFMC 2002
Red hake	X	X	X	X	X	NEFMC 1998; Steimle et al. 1999d
Redfish	*	*	*	*	*	NEFMC 1998; Pikanowski et al. 1999
Rosette skate	*	*	*	*	*	NEFMC 2003; Packer et al. 2003d
Scup	*	*	X	X	*	MAFMC and ASMFC 1998a; Steimle et al. 1999e; MMS 2009
Sea scallop	*	*	*	*	*	NEFMC 1998; Packer et al. 1999a
Silver hake	X	X	X	X	*	Morse et al. 1999; Lock et al. 2004
Smooth skate	*	*	*	*	*	NEFMC 2003; Packer et al. 2003e
Spanish mackerel	X	X	X	X	X	SAFMC1998; MMS 2009
Spiny dogfish	*	*	X	X	*	McMillan and Morse 1999; MAFMC and NEFMC 1999
Summer flounder	X	X	X	X	*	Packer et al. 1999b; MMS 2009
Thorny skate	*	*	*	*	*	NEFMC 2003; Packer et al. 2003f
Tilefish	X	X	X	X	X	Steimle et al. 1999f; MAFMC 2000
White hake	X	X	X	X	X	NEFMC 1998; Chang et al. 1999b
Windowpane flounder	X	X	X	X	X	NEFMC 1998; Chang et al. 1999c; MMS 2009
Winter flounder	X	X	X	X	X	NEFMC 1998; Pereira et al. 1999; MMS 2009
Winter skate	*	*	X	X	*	NEFMC 2003; Packer et al. 2003g; MMS 2009
Witch flounder	X	X	X	X	X	NEFMC 1998; Cargnelli et al. 1999h
Yellowtail flounder	X	X	X	X	X	NEFMC 1998; Johnson et al. 1999b; MMS 2009

TABLE 8. Highly migratory species, excluding sharks, with Essential Fish Habitat (EFH) in the study area. Species and stages with EFH in Nantucket Sound are shaded in gray. * = information currently unavailable; X = EFH present. Source: DoN (2005); MMS 2009.

Species	Eggs	Larvae	Juvenile	Sub-adults	Adults	Spawning Adults
Albacore tuna	*	*	X	X	X	*
Bigeye tuna	*	*	X	X	X	*
Blue marlin	*	*	*	*	*	*
Bluefin tuna	*	*	X	X	X	*
Skipjack tuna	*	*	*	*	*	*
Swordfish	*	*	*	*	X	*
White marlin	*	*	X	X	X	*
Yellowfin tuna	*	*	X	X	X	*

TABLE 9. Shark species with Essential Fish Habitat (EFH) in the study area. Species and stages with EFH in Nantucket Sound are shaded in gray. * = information currently unavailable; X = EFH present. Source: DoN (2005); MMS 2009.

Species	Neonates	Early Juveniles	Late Juveniles	Subadults	Adults
Atlantic angel shark	*	*	*	*	*
Atlantic sharpnose shark	*	*	*	*	*
Basking shark	*	*	X	X	X
Blue shark	*	*	X	X	X
Dusky shark	*	X	X	*	*
Longfin mako shark	X	X	X	X	X
Porbeagle shark	X	X	X	X	X
Sand tiger shark	*	*	*	*	*
Sandbar shark	*	X	X	X	X
Scalloped hammerhead	*	*	*	*	*
Shortfin mako shark	X	X	X	X	X
Thresher shark	X	X	X	X	X
Tiger shark	*	*	X	X	*
White shark	*	*	*	*	*

should be considered EFH. HAPCs are identifiable, uniquely important areas necessary to support healthy stocks of fish throughout all of their life stages. However, healthy populations of fish require not only the relatively small habitats identified as HAPCs, but also other suitable areas that provide habitat functions that are necessary to support large numbers of fish, promoting sustainable fisheries and a healthy ecosystem. In total, HAPCs comprise only a fraction of 1 percent of the areas identified as EFH." (NMFS 2008d).

HAPC are a subset of EFH that provide highly important ecological functions or are especially vulnerable to degradation. "The EFH regulations require that designation of specific HAPCs be based on one or more of the following considerations (Dobrzynski and Johnson 2001):

a the importance of the ecological function provided by the habitat;

b the extent to which the habitat is sensitive to human-induced environmental degradation;

c whether and to what extent development activities are or will be stressing the habitat; and

d the rarity of the habitat type.

Four species (Atlantic cod; summer flounder; tilefish; and sandbar shark *Carcharhinus plumbeus*) have HAPC designated in waters off the northeast U.S. coast, but only two of those (summer flounder and tilefish) have HAPC within or adjacent to the proposed study area. Juvenile cod HAPC, located outside of the proposed study area, consists of a 300-n.mi.^{2} benthic area along the northern flank of Georges Bank consisting of gravel or cobble (NEFMC 1998). For the juvenile and adult life stages of summer flounder, HAPC is considered to include all native species of macroalgae, seagrasses, and freshwater and tidal macrophytes, whether found as small aggregations or in beds, located within the adult and juvenile summer flounder EFH (DoN 2005). Juvenile and adult summer flounder HAPC may occur in the proposed study area. The HAPC for the juvenile and adult life stages of tilefish is designated as the rocky, exposed ledges and stiff clay substrate between the 76-m and 366-m isobaths in the northeast region of statistical areas 616 and 537 (MAFMC 2000). The proposed study area is in Statistical Area 537; outer continental shelf seismic lines deeper than 76 m will encroach upon juvenile and adult tilefish HAPC. The HAPC designated for sandbar shark occurs in coastal waters south of New York (McCandles et al. 2002 *in* DoN 2005; NMFS 2003), outside of the proposed study area.

Corals

Scleractinian, alcyonarian, gorgonian, and pennatularian corals can be found in nearshore shallow water areas of the inner continental shelf as well as deeper waters along the continental slope, canyons, deep channels, and seamounts of the NWA (Watling 2001). None of these corals are listed under the ESA. Members of these coral communities can be found near the rocky shorelines and inner continental shelf waters around MV (see Fig. 4-2 *in* DoN 2005). Deep-water corals occur across the continental shelf in the NWA, but are most common on the continental slope and in submarine canyons, gullies, and on seamounts (Breeze et al. 1997). DoN (2005) identifies several locations of deep-water alcyonarian corals and multi-species coral communities along the continental slope to the south and east of the proposed study area, including submarine canyons such as the Veatch, Atlantis, and Alvin Canyons.

IV. ENVIRONMENTAL CONSEQUENCES

Proposed Action

(1) Direct Effects and Their Significance

The material in this section includes a summary of the anticipated effects (or lack thereof) on marine mammals and sea turtles of airguns, including the GI guns to be used by Rice. A more detailed review of airgun effects on marine mammals appears in Appendix A. That Appendix is little changed from corresponding parts of previous EAs and associated IHA applications concerning other seismic surveys by oceanographic institutions since 2003, but was updated in 2009. Appendix B contains a general review of the effects of seismic pulses on sea turtles.

This section also includes a discussion of the potential impacts of operations by an echosounder, SBP, and boomer system.

Finally, this section includes estimates of the numbers of marine mammals that might be affected by the proposed activity during the seismic survey scheduled to occur off New England during 12–25 August 2009. A description of the rationale for Rice’s estimates of the potential numbers of harassment “takes” during the planned seismic program is also provided.

(a) 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; Weilgart 2007). Permanent hearing impairment, in the unlikely event that it occurred, would constitute injury, but temporary threshold shift (TTS) is not an injury (Southall et al. 2007). 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 readily detectable in the water at distances of many kilometers. For a brief summary of the characteristics of airgun pulses, see Appendix A (3). However, it should be noted that most of the measurements of airgun sounds that have been reported concerned sounds from larger arrays of airguns, whose sounds would be detectable considerably farther away than the GI guns planned for use in the present project.

Several studies have shown that marine mammals at distances more than a few kilometers from operating seismic vessels often show no apparent response—see Appendix A (5). 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. During active seismic surveys, sea turtles typically do not show overt reactions to airgun pulses, although some very localized avoidance can occur. Given the relatively small and low-energy airgun source planned for use in this project, mammals (and sea turtles) are expected to tolerate being closer to this source than might be the case for a larger airgun source typical of most seismic surveys.

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 some situations, multi-path arrivals and reverberation cause airgun sound to arrive for much or all of the interval between pulses (e.g., Simard et al. 2005; Clark and Gagnon 2006), which could mask calls. Some baleen and toothed whales are known to continue calling in the presence of seismic pulses, and their calls usually can be heard between the seismic pulses (e.g., Richardson et al. 1986; McDonald et al. 1995; Greene et al. 1999; Nieukirk et al. 2004; Smultea et al. 2004; Holst et al. 2005a,b, 2006). In the northeast Pacific Ocean, blue whale calls have been recorded during a seismic survey off Oregon (McDonald et al. 1995). Among 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 found that this species continued calling in the presence of seismic pulses (Madsen et al. 2002; Tyack et al. 2003; Smultea et al. 2004; Holst et al. 2006; Jochens et al. 2006, 2008). Dolphins and porpoises commonly are heard calling while airguns are operating (e.g., Gordon et al. 2004; Smultea et al. 2004; Holst et al. 2005a,b; Potter et al. 2007). 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 negligible, given the normally intermittent nature of seismic pulses and the relatively low source level of the airguns to be used here. Masking effects on marine mammals are discussed further in Appendix A (4). We are not aware of any information concerning masking of hearing in sea turtles.

Disturbance Reactions—Disturbance includes a variety of effects, including subtle to conspicuous changes in behavior, movement, and displacement. Based on NMFS (2001, p. 9293), NRC (2005), and

Southall et al. (2007), we assume that simple exposure to sound, or brief reactions that do not disrupt behavioral patterns in a potentially significant manner, do not constitute harassment or "taking". By potentially significant, we mean "in a manner that might have deleterious effects to the well-being of individual marine mammals or their populations".

Reactions to sound, if any, depend on species, state of maturity, experience, current activity, reproductive state, time of day, and many other factors (Richardson et al. 1995; Wartzok et al. 2004; Southall et al. 2007; Weilgart 2007). 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. 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 could be disturbed to some biologically-important degree by a seismic program are based primarily on behavioral observations of a few species. Detailed studies have been done on humpback, gray, bowhead, and sperm whales, and on ringed seals. Less detailed data are available for some other species of baleen whales, small toothed whales, and sea otters, but for many species there are no data on responses to marine seismic surveys. Most of those studies have concerned reactions to much larger airgun sources than planned for use in the proposed project. Thus, effects are expected to be limited to considerably smaller distances and shorter periods of exposure in the proposed project than in most of the previous work concerning marine mammal reactions to airguns.

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, as reviewed in Appendix A (5), 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.

Studies of gray, bowhead, and humpback whales have shown that seismic pulses with received 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 to 15 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 studies summarized in Appendix A (5) have shown that 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}. Reaction distances would be considerably smaller during the proposed project, in which the 160-dB radius is predicted to be ~1029 m in shallow waters (Table 1), as compared with several kilometers when a large array of airguns is operating.

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. McCauley et al. (1998, 2000a) studied the responses of 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 source level 227 dB re 1 μPa·m$_{p\text{–}p}$. McCauley et al. (1998) documented that avoidance reactions began at 5–8 km from the array, and that those reactions kept most pods ~3–4 km from the operating seismic boat. McCauley et al. (2000a) noted localized displacement during migration of 4–5 km by traveling pods and 7–12 km by more sensitive resting pods of cow-calf pairs. Avoidance distances with respect to the single airgun were smaller but consistent with the results from the full array in terms of the received sound levels. The mean received level for initial avoidance of an approaching airgun was 140 dB re 1 μPa$_{rms}$ for humpback pods containing females, and at the mean closest point of approach (CPA) distance, the received level was 143 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 level was 179 dB re 1 μPa$_{rms}$.

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 levels 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 levels up to 172 re 1 μPa on an approximate rms basis.

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 of the humpback sightings when airguns were on vs. off (3050 m vs. 2700 m, respectively).

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. After allowance for data from subsequent years, there was "no observable direct correlation" between strandings and seismic surveys (IWC 2007b: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 around 120–130 dB re 1 μPa$_{rms}$ [Miller et al. 1999; Richardson et al. 1999; see Appendix A (5)]. 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. Nonetheless, subtle but statistically significant changes in surfacing–respiration–dive cycles were evident upon statistical analysis (Richardson et al. 1986). In summer, bowheads 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).

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}. 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), and western Pacific gray whales feeding off Sakhalin Island, Russia (Würsig et al. 1999; Gailey et al. 2007; Johnson et al. 2007; Yazvenko et al. 2007a,b), along with data on gray whales off British Columbia (Bain and Williams 2006). Gray whales typically show no conspicuous responses to airgun pulses with received levels up to 150–160 dB re 1 μPa_{rms}, but are increasingly likely to show avoidance as received levels increase above that range.

Various species of *Balaenoptera* (blue, sei, fin, and minke whales) have occasionally been reported in areas ensonified by airgun pulses (Stone 2003; MacLean and Haley 2004; Stone and Tasker 2006). 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 shooting 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 (Stone and Tasker 2006). In a study off Nova Scotia, Moulton and Miller (2005) found little difference in sighting rates (after accounting for water depth) and initial sighting distances of balaenopterid whales when airguns were operating vs. silent. However, there were indications that these whales were more likely to be moving away when seen during airgun operations. Similarly, ship-based monitoring studies of blue, fin, sei and minke whales offshore of Newfoundland (Orphan Basin and Laurentian Sub-basin) found no more than small differences in sighting rates and swim directions during seismic vs. non-seismic periods (Moulton et al. 2005, 2006a,b).

Data on short-term reactions by cetaceans to impulsive noises are not necessarily indicative of long-term or biologically significant effects. It is not known whether impulsive sounds affect reproductive rate or distribution and habitat use in subsequent days or years. However, gray whales have continued to migrate annually along the west coast of North America with substantial increases in the population over recent years, despite intermittent seismic exploration (and much ship traffic) in that area for decades (Appendix A *in* Malme et al. 1984; Richardson et al. 1995; Angliss and Outlaw 2008). 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, despite seismic exploration in their summer and autumn range for many years (Richardson et al. 1987; Angliss and Outlaw 2008). In any event, the brief exposures to sound pulses from the present small airgun source are highly unlikely to result in prolonged effects.

Toothed Whales.—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 and (in more detail) in Appendix A have been reported for toothed whales. However, there are recent systematic studies on sperm whales (Jochens et al. 2006, 2008; Miller et al. 2006). 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).

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). Some dolphins seem to be attracted to the seismic vessel and floats, and some ride the bow wave of the seismic vessel even when large arrays of airguns are 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). In most cases the avoidance radii for delphinids appear to be small, on the order of 1 km less, and some individuals show no apparent avoidance.

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. Although the ramp-up procedure is a widely-used mitigation measure, it remains uncertain whether it is effective or not at alerting marine mammals and causing them to move away from seismic operations (Weir 2008b).

The beluga is a species that (at least at times) shows long-distance avoidance of seismic vessels. Aerial surveys conducted in the southeastern Beaufort Sea during summer found that sighting rates of beluga whales were significantly lower at distances 10–20 km compared with 20–30 km from an operating airgun array, and observers on seismic boats in that area rarely see belugas (Miller et al. 2005; Harris et al. 2007).

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). However, the animals tolerated high received levels of sound before exhibiting aversive behaviors.

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 (Stone 2003; MacLean and Koski 2005; Bain and Williams 2006; Stone and Tasker 2006). 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). 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 (e.g., Stone 2003; Moulton et al. 2005, 2006a; Jochens et al. 2006, 2008; Stone and Tasker 2006; Weir 2008a). In most cases, the whales do not show strong avoidance and continue to call (see Appendix A for review). However, controlled exposure experiments in the Gulf of Mexico indicate that foraging behavior was altered upon exposure to airgun sound (Jochens et al. 2006, 2008). In the SWSS study, 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 sound exposures of airgun arrays in the Gulf of Mexico (Jochens et al. 2008). Whales were exposed to maximum received sound levels between 111 and 147 dB re 1 μPa_{rms} (131–164 dB re 1 μPa_{pk-pk}) at ranges of ~1.4–12.6 km from the sound source. Although the tagged whales showed no horizontal avoidance, some whales changed foraging behavior during full-array exposure (Jochens et al. 2008).

There are almost no specific data on the behavioral reactions of beaked whales to seismic surveys. However, northern bottlenose whales continued to produce high-frequency clicks when exposed to sound pulses from distant seismic surveys (Laurinolli and Cochrane 2005; Simard et al. 2005). Most beaked whales tend to avoid approaching vessels of other types (e.g., Würsig et al. 1998). 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. 2006). In any event, it is likely that most beaked whales would also show strong avoidance of an approaching seismic vessel, although this apparently has not been documented explicitly.

There are increasing indications that some beaked whales tend to strand when naval 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; Hildebrand 2005; Barlow and Gisiner 2006; 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 involved. Whether beaked whales would ever react similarly to seismic surveys is unknown (see “Strandings and Mortality”, below). Seismic survey sounds are quite different from those of the sonars in operation during the above-cited incidents, and in particular, the dominant frequencies in airgun pulses are at lower frequencies than used by mid-frequency naval sonars.

Odontocete reactions to large arrays of airguns are variable and, at least for delphinids and some porpoises (e.g., Dall’s), seem to be confined to a smaller radius than has been observed for the more responsive of the mysticetes, belugas, and harbor porpoises (Appendix A). A ≥170 dB re 1 μPa_{rms} disturbance criterion (rather than ≥160 dB) is considered appropriate for delphinids (and pinnipeds), which tend to be less responsive than most other cetaceans.

Pinnipeds.—In the event that any pinnipeds are encountered, they are not likely to show a strong avoidance reaction to the 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—see Appendix A (5). In the Beaufort Sea, some ringed seals avoided an area of 100 m to (at most) a few hundred meters around seismic vessels, but many seals remained within 100–200 m of the trackline as the operating airgun array passed by (e.g., Harris et al. 2001; Moulton and Lawson 2002; Miller et al. 2005). Ringed seal sightings averaged somewhat farther away from the seismic vessel when the airguns were operating than when they were not, but the difference was small (Moulton and Lawson 2002). Similarly, in Puget Sound, sighting distances for harbor seals and California sea lions tended to be larger when airguns were operating (Calambokidis and Osmek 1998). Previous telemetry work suggests that avoidance and other behavioral reactions may be stronger than evident to date from visual studies (Thompson et al. 1998). Nonetheless, reactions are expected to be confined to relatively small distances and durations, with no long-term effects on pinniped individuals or populations. As for delphinids, a ≥170 dB disturbance criterion is considered appropriate for pinnipeds, which tend to be less responsive than many cetaceans.

Sea Turtles.—The limited available data indicate that sea turtles will hear airgun sounds and sometimes exhibit localized avoidance (see Appendix B). Based on available data, it is likely that sea turtles will exhibit behavioral changes and/or avoidance within an area of unknown size near a seismic vessel (e.g., Holst et al. 2006; Weir 2007; Hauser et al. 2008; Holst and Smultea 2008). Observed responses of sea turtles to airguns are reviewed in Appendix B. To the extent that there are any impacts on sea turtles, seismic operations in or near areas where turtles concentrate are likely to have the greatest impact. There are no specific data that demonstrate the consequences to sea turtles if seismic operations with large (or small) arrays of airguns occur in important areas at biologically important times of year.

Hearing Impairment and Other Physical Effects—Temporary or permanent hearing impairment is a possibility when marine mammals are exposed to very strong sounds. TTS has been demonstrated and studied in certain captive odontocetes (and pinnipeds) exposed to strong sounds (reviewed 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 exclusion (=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. As discussed in Appendix A (6) and below,

- the 180-dB criterion for cetaceans is probably quite precautionary, i.e., lower than necessary to avoid temporary auditory impairment let alone permanent auditory injury, at least for delphinids.
- TTS is not injury and does not constitute "Level A harassment" in U.S. MMPA terminology.
- 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 noise exposure criteria for marine mammals, frequency-weighting procedures, and related matters were published recently (Southall et al. 2007). Those recommendations have not, as of early 2009, been formally adopted by NMFS for use in regulatory processes and during mitigation programs associated with seismic surveys. However, some aspects of the recommendations have been taken into account in certain Environmental Impact Statements (EISs) and small-take authorizations. NMFS has indicated that it may issue new noise exposure criteria for marine mammals that account for the now-available 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, and other relevant factors. Preliminary information about possible changes in the regulatory and mitigation requirements, and about the possible structure of new criteria, was given by Wieting (2004) and NMFS (2005b).

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 § 2.3.1.1, "Monitoring and Mitigation Measures"). In addition, many cetaceans and (to a limited degree) pinnipeds and sea turtles show some avoidance of the area where received levels of airgun sound are high enough such that hearing impairment could potentially occur. In those cases, the avoidance responses of the animals themselves will reduce or (most likely) prevent any 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 in mammals close to a strong sound source include stress, neurological effects, bubble formation, and other types of organ or tissue damage. It is possible that some marine mammal species (particularly beaked whales) may be especially susceptible to injury and/or stranding when exposed to strong transient sounds. However, as discussed below, there is no definitive evidence that any of these effects occur even for marine mammals in close proximity to large arrays of airguns. It is unlikely that any effects of these types would occur during the proposed project given the small size of the airgun source (two 45-in^3 GI guns) and the planned monitoring and mitigation measures (see below). The following subsections discuss in somewhat more detail the possibilities of TTS, PTS, and non-auditory physical effects.

Temporary Threshold Shift.—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. At least in terrestrial mammals, TTS can last from minutes or hours to (in cases of strong TTS) days. For sound exposures at or somewhat above the TTS threshold, hearing sensitivity in both terrestrial and marine mammals recovers rapidly after exposure to the noise ends. Few data on sound levels and durations necessary to elicit mild TTS have been obtained for marine mammals, and none of the published data concern TTS elicited by exposure to multiple pulses of sound. Available data on TTS in marine mammals are compiled and summarized in Southall et al. (2007).

For toothed whales exposed to single short pulses, the TTS threshold appears to be, to a first approximation, a function of the energy content of the pulse (Finneran et al. 2002, 2005). Given the available data, the received energy level of a single seismic pulse (with no frequency weighting) might need to be ~186 dB re 1 $\mu Pa^2 \cdot s$ (i.e., 186 dB SEL or ~196–201 dB re 1 μPa_{rms}) in order to produce brief, mild TTS[2]. Exposure to several strong seismic pulses that each have received levels near 190 dB re 1 μPa_{rms} (175–180 dB SEL) might result in cumulative exposure of ~186 dB SEL and thus slight TTS in a small odontocete, assuming the TTS threshold is (to a first approximation) a function of the total received pulse energy. Levels ≥190 dB re 1 μPa_{rms} are expected to be restricted to radii no more than 147 m from the *Endeavor*'s GI guns. For an odontocete closer to the surface, the maximum radius with ≥190 dB re 1 μPa_{rms} would be smaller.

The above TTS information for odontocetes is derived from studies on the bottlenose dolphin and beluga. There is no published TTS information for other types of cetaceans. However, preliminary evidence from a harbor porpoise exposed to airgun sound suggests that its TTS threshold may have been lower (Lucke et al. 2007).

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). From this, it is suspected that received levels causing TTS onset may also be higher in baleen whales (Southall et al. 2007). In any event, no cases of TTS are expected given three considerations: (1) small size of the airgun source (two 45-in^2 GI guns); (2) the strong likelihood that baleen whales would avoid the approaching GI guns (or vessel) before being exposed to levels high enough for TTS to occur; and (3) the mitigation measures that are planned.

In pinnipeds, TTS thresholds associated with exposure to brief pulses (single or multiple) of underwater sound have not been measured. Initial evidence from more prolonged (non-pulse) exposures suggested that some pinnipeds (harbor seals in particular) incur TTS at somewhat lower received levels than do small odontocetes exposed for similar durations (Kastak et al. 1999, 2005; Ketten et al. 2001). The TTS threshold for pulsed sounds has been indirectly estimated as being an SEL of ~171 dB re 1 $\mu Pa^2 \cdot s$ (Southall et al. 2007), which would be equivalent to a single pulse with received level ~181–186 dB re 1 $\mu Pa_{rms,}$ or a series of pulses for which the highest rms values are a few dB lower. Corresponding values for California sea lions and northern elephant seals are likely to be higher (Kastak et al. 2005).

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[2] If the low frequency components of the watergun sound used in the experiments of Finneran et al. (2002) are downweighted as recommended by Miller et al. (2005) and 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).

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), data that are now available imply that TTS is unlikely to occur in most odontocetes (and probably mysticetes as well) unless they are exposed to a sequence of several airgun pulses in which the strongest pulse has a received level substantially exceeding 180 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.—When PTS occurs, there is physical damage to the sound receptors in the ear. In severe 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).

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*). Single or occasional occurrences of mild TTS are not indicative of permanent auditory damage.

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. PTS could occur at a received sound level at least several decibels above that inducing mild TTS if the animal were exposed to strong sound pulses with rapid rise time—see Appendix A (6). 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. (2007:441-4) 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 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). 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 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. A peak pressure of 230 dB re 1 μPa (3.2 bar·m) would only be found within a few meters of the largest (600-in^3) airguns in most airgun arrays (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 and sea turtles. The planned monitoring and mitigation measures, including visual monitoring and shut downs of the GI guns when mammals are seen within or approaching the "safety radii", will further reduce the probability of exposure of marine mammals to sounds strong enough to induce PTS.

Non-auditory Physiological Effects.—Non-auditory physiological effects or injuries that theoretically might occur in marine mammals exposed to strong underwater sound include stress, neurological effects, bubble formation, resonance, and other types of organ or tissue damage (Cox et al. 2006; Southall et al. 2007). Studies examining such effects are limited. 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. 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 of this upon exposure to airgun pulses.

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, 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 those ways. Marine mammals that show behavioral avoidance of seismic vessels, including most baleen whales and some odontocetes, are especially unlikely to incur non-auditory physical effects. Also, proposed mitigation measures [§ VI] including shut downs of the GI guns, would reduce any such effects that might otherwise occur.

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 for marine seismic research or commercial seismic surveys, and have been replaced entirely by airguns or related non-explosive pulse generators. 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, an L-DEO 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). Appendix A (6) provides additional details.

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. As noted in the preceding subsection, 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).

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. A further difference between seismic surveys and naval exercises is that naval exercises can involve sound sources on more than one vessel. 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. However, 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.

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. 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 2007b). In Sept. 2002, there was a stranding of two Cuvier's beaked whales in the Gulf of California, Mexico, when the L-DEO 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). Nonetheless, the Gulf of California incident plus the beaked whale strandings near naval exercises involving use of mid-frequency sonar suggests 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).

No injuries of beaked whales are anticipated during the proposed study because of (1) the high likelihood that any beaked whales 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.

Sea Turtles.—The limited available data indicate that the frequency range of best hearing sensitivity by sea turtles extends from roughly 250–300 Hz to 500–700 Hz; sensitivity deteriorates at lower or higher frequencies. However, there is some sensitivity to frequencies as low as 60 Hz, and probably as low as 30 Hz. Thus, there is substantial overlap in the frequencies that sea turtles detect vs. the frequencies in airgun pulses. We are not aware of measurements of the absolute hearing thresholds of any sea turtle to waterborne sounds similar to airgun pulses. In the absence of relevant absolute threshold data, we cannot estimate how far away an airgun array might be audible. TTS apparently occurred in loggerhead turtles exposed to many pulses from a single airgun ≤65 m away (see Moein et al. [1994] and Appendix B). This suggests that sounds from an airgun array might cause temporary hearing impairment in sea turtles if they do not avoid the (unknown) radius where TTS occurs. However, exposure duration during the planned surveys would be much less than during the study by Moein et al. (1994). Also, recent monitoring studies show that some sea turtles do show localized movement away from approaching airguns (Holst et al. 2006; Weir 2007; Hauser et al. 2008; Holst and Smultea 2008). At short distances from the source, received sound level diminishes rapidly with increasing distance. In that situation, even a small-scale avoidance response could result in a significant reduction in sound exposure.

As noted above, the MMOs stationed on the *Endeavor* will also watch for sea turtles, and airgun operations will be shut down if a turtle enters the designated exclusion zone.

(b) Possible Effects of Echosounder Signals

The Knudsen echosounder will be operated from the source vessel during most of the proposed study. Information about the equipment was provided in § II(2). Sounds from the echosounder are short pulses, occurring for up to 24 ms once every few seconds. Most of the energy in the sound pulses is at 3.5 and 12 kHz, and the beam is directed downward. The source level of the echosounder is expected to be relatively low compared to the GI guns. Kremser et al. (2005) noted that the probability of a cetacean swimming through the area of exposure when an echosounder emits a pulse is small, and if the animal was in the area, it would have to pass the transducer at close range in order to be subjected to sound levels that could cause TTS.

Masking—Marine mammal communications will not be masked appreciably by the echosounder signals given their directionality and the brief period when an individual mammal is likely to be within its beam. Furthermore, in the case of most baleen whales, the signals do not overlap with the predominant frequencies in the calls, which would avoid significant masking.

Behavioral Responses—Behavioral reactions of free-ranging marine mammals to echosounders and other sound sources appear to vary by species and circumstance. Observed reactions have included silencing and dispersal by sperm whales (Watkins et al. 1985), increased vocalizations and no dispersal by pilot whales (Rendell and Gordon 1999), and the previously-mentioned beachings by beaked whales. During exposure to a 21–25 kHz whale-finding sonar with a source level of 215 dB re 1 µPa·m, gray whales showed slight avoidance (~200 m) behavior (Frankel 2005). When a 38-kHz echosounder and a 150-kHz acoustic Doppler current profiler were transmitting during studies in the Eastern Tropical Pacific, baleen whales showed no significant responses, while spotted and spinner dolphins were detected slightly more often and beaked whales less often during visual surveys (Gerrodette and Pettis 2005).

During a previous low-energy seismic survey from the R/V *Thomas G. Thompson,* several echosounders were in operation most of the time, and a fathometer was also used during part of the survey. Many cetaceans and small numbers of fur seals were seen by the MMOs aboard the ship, but no specific information about echosounder effects (if any) on mammals were obtained (Ireland et al. 2005). These responses (if any) could not be distinguished from responses to the GI guns (when operating) and to the ship itself.

Captive bottlenose dolphins and a white whale exhibited changes in behavior when exposed to 1 s pulsed sounds at frequencies of ~30 kHz and to shorter broadband pulsed signals. Behavioral changes typically involved what appeared to be deliberate attempts to avoid the sound exposure (Schlundt et al. 2000; Finneran et al. 2002; Finneran and Schlundt 2004). The relevance of those data to free-ranging odontocetes is uncertain, and in any case, the test sounds were quite different in either duration or bandwidth as compared with those from an echosounder.

Very few data are available on the reactions of pinnipeds to echosounder sounds at frequencies similar to those used during seismic operations. Hastie and Janik (2007) conducted a series of behavioral response tests on two captive gray seals to determine their reactions to underwater operation of a 375-kHz multibeam imaging sonar that included significant signal components down to 6 kHz. Results indicated that the two seals reacted to the sonar signal by significantly increasing their dive durations. Based on observed pinniped responses to other types of pulsed sounds, and the likely brevity of exposure to the echosounder sounds, pinniped reactions are expected to be limited to startle or otherwise brief responses of no lasting consequence to the animals.

During the proposed operations, the individual pulses will be very short, and a given mammal would not receive many of the downward-directed pulses as the vessel passes by. In the case of baleen whales, the echosounder will operate at too high a frequency to have any effect. As noted earlier, NMFS (2001) has concluded that momentary behavioral reactions "do not rise to the level of taking". Thus, brief exposure of cetaceans or pinnipeds to small numbers of signals from the echosounder would not result in a "take" by harassment, even if a brief reaction did occur.

Hearing Impairment and Other Physical Effects—Given recent stranding events that have been associated with the operation of naval sonar, there is concern that mid-frequency sonar sounds can cause serious impacts to marine mammals (see above). However, the echosounder proposed for use is quite different than sonars used for navy operations. Pulse duration of the echosounder is very short relative to naval sonars. Also, at any given location, an individual marine mammal would be in the beam of the echosounder for much less time given its generally downward orientation; navy sonars often use near-horizontally-directed sound.

Given the maximum source level of 211 dB re 1 μPa·m rms (see § II), the received energy level from a single pulse of duration 24 ms would be ~195 dB re 1 $\mu Pa^2 \cdot s$ at 1 m, i.e., 211 dB + 10 log (0.024 s). As the TTS threshold for a cetacean receiving a single non-impulse sound is 195 dB re 1 $\mu Pa^2 \cdot s$ and the anticipated PTS threshold is 215 dB re 1 $\mu Pa^2 \cdot s$ (Southall et al. 2007), it is very unlikely that an animal would ever come close enough to the transducer to incur TTS (which would be fully recoverable), let alone PTS. As noted by Burkhardt et al. (2007, 2008), cetaceans are very unlikely to incur PTS from operation of scientific echosounders on a ship that is underway.

For the harbor seal, the TTS threshold for non-impulse sounds is ~183 dB re 1 $\mu Pa^2 \cdot s$, as compared with ~195 dB re 1 $\mu Pa^2 \cdot s$ in odontocetes (Kastak et al. 2005; Southall et al. 2007). TTS onset occurs at higher received energy levels in the California sea lion and northern elephant seal than in the harbor seal. The received level for a harbor seal within the echosounder beam 10 m below the ship would be ~191 dB re 1 μPa_{rms}, assuming 40 dB of spreading loss over 100 m (circular spreading). Given the narrow beam, only one pulse is likely to be received by a given animal as the ship passes overhead. At 10 m, the received energy level from a single pulse of duration 24 ms would be ~175 dB re 1 $\mu Pa^2 \cdot s$, i.e., 191 dB + 10 log (0.024 s). Thus, a harbor seal would have to come very close to the transducer in order to receive a single echosounder pulse with a received energy level of ≥183 dB re 1 $\mu Pa^2 \cdot s$. Given the intermittent nature of the signals and the narrow echosounder beam, only a small fraction of the pinnipeds below (and close to) the ship would receive a pulse as the ship passed overhead. Thus, it seems unlikely that a pinniped would incur TTS, let along PTS, if exposed to a single pulse by the echosounder.

Sea Turtles—It is unlikely that echosounder operations during the planned seismic survey would significantly affect sea turtles through masking, disturbance, or hearing impairment. Any effects would likely be negligible given the brief exposure and the fact that the echosounder frequency is above the range of optimal hearing by sea turtles (see Appendix B).

(c) Possible Effects of the Sub-bottom Profiler Signals

A SBP will be operated from the source vessel at times during the planned study. Details about this equipment were provided in § II(2). Sounds from the SBP are relatively short pulses, occurring for 30 ms once every 0.5 to 1 s. The SBP will transmit a 0.5-12 kHz swept pulse (or chirp). The source level of the SBP is expected to be similar to or less than that of the Knudsen echosounder. Kremser et al. (2005) noted that the probability of a cetacean swimming through the area of exposure when a SBP emits a pulse is small—if the animal was in the area, it would have to pass the transducer at close range and in order to be subjected to sound levels that could cause TTS.

Masking.—Marine mammal communications will not be masked appreciably by the SBP signals given the brief period when an individual mammal is likely to be within its beam.

Behavioral Responses.—Marine mammal behavioral reactions to other pulsed sound sources are discussed above, and responses to the SBP are likely to be similar to those for other pulsed sources if received at the same levels. Behavioral responses are not expected unless marine mammals are very close to the source.

Hearing Impairment and Other Physical Effects.—It is unlikely that the SBP produces pulse levels strong enough to cause hearing impairment or other physical injuries even in an animal that is (briefly) in a position near the source. The SBP is usually operated simultaneously with other higher-power acoustic sources. Many marine mammals will move away in response to the approaching higher-power sources or the vessel itself before the mammals would be close enough for there to be any possibility of effects from the less intense sounds from the SBP. In the case of mammals that do not avoid the approaching vessel and its various sound sources, mitigation measures that would be applied to minimize effects of other sources [see § II(3)] would further reduce or eliminate any minor effects of the SBP.

Sea Turtles.—It is very unlikely that SBP operations during the planned seismic survey would significantly affect sea turtles through masking, disturbance, or hearing impairment. Any effects likely would be negligible given the brief exposure and relatively low source level.

(d) Possible Effects of the Boomer

The Boomer will be operated from the source vessel at times during the planned study. Details about this equipment were provided in § II(2). Sounds from the Boomer are very short pulses, occurring for 0.1 ms once every second. The Boomer will transmit a 0.3 to 3 kHz pulse. The source level of the Boomer is similar to that of the Knudsen echosounder—212 dB re 1 µPa·m. If the animal was in the area, it would have to pass the transducer at close range and in order to be subjected to sound levels that could cause TTS.

Masking.—Marine mammal communications will not be masked appreciably by the Boomer signals given the directionality and brief period when an individual mammal is likely to be within its beam.

Behavioral Responses.—Marine mammal behavioral reactions to other pulsed sound sources are discussed above, and responses to the Boomer are likely to be similar to those for other pulsed sources if received at the same levels. Behavioral responses are not expected unless marine mammals are very close to the source.

Hearing Impairment and Other Physical Effects.—It is unlikely that the Boomer produces pulse levels strong enough to cause hearing impairment or other physical injuries even in an animal that is (briefly) in a position near the source. The Boomer will be operated simultaneously with the higher-power GI guns. Many marine mammals will move away in response to the approaching GI guns or the vessel itself before the mammals would be close enough for there to be any possibility of effects from the less intense sounds from the Boomer. In the case of mammals that do not avoid the approaching vessel and its various sound sources, mitigation measures that would be applied to minimize effects of other sources [see § II(3)] would further reduce or eliminate any minor effects of the Boomer.

Sea Turtles.—It is very unlikely that Boomer operations during the planned seismic survey would significantly affect sea turtles through masking, disturbance, or hearing impairment. Any effects likely would be negligible given the brief exposure and relatively low source level.

(2) Mitigation Measures

Several mitigation measures are built into the proposed seismic survey as an integral part of the planned activities. These measures include the following: ramp ups, a minimum of one dedicated observer maintaining a visual watch during all daytime airgun operations, two observers for 30 min before and during ramp-ups during the day and at night (and when possible at other times), shut downs when mammals or turtles are detected in or about to enter designated exclusion zones, power downs during turns, and additional special measures applicable to North Atlantic right whales and concentrations of humpback, sperm, blue, sei, and fin whales. These mitigation measures are described earlier in this document, in § II(3).

Previous and subsequent analysis of the potential impacts take account of these planned mitigation measures. It would not be meaningful to analyze the effects of the planned activities without mitigation, as the mitigation (and associated monitoring) measures are a basic part of the activities.

(3) Numbers of Marine Mammals that Could be "Taken by Harassment"

All anticipated takes would be "takes by harassment" as described in § I, involving temporary changes in behavior. The mitigation measures to be applied will minimize the possibility of injurious takes. (However, as noted earlier and in Appendix A, there is no specific information demonstrating that injurious "takes" would occur even in the absence of the planned mitigation measures.) In the sections below, we describe methods to estimate "take by harassment", and present estimates of the numbers of marine mammals that might be affected during the proposed seismic survey in the NWA. The estimates are based on data concerning (1) cetacean densities (numbers per unit area) obtained during aerial surveys off New England during 2002 and 2004 by NMFS/Northeast Fisheries Science Center (NEFSC), and (2) estimates of the size of the area where effects could potentially occur. Few, if any, pinnipeds are expected to be encountered during the proposed survey in the summer (see § III).

The following estimates are based on a consideration of the number of marine mammals that could be disturbed appreciably by operations with the GI guns to be used during ~1757 line-km of surveys (including turns) south off the New England coast. The anticipated radii of influence of the other sound sources (i.e., a sub-bottom profiler, boomer system, and echosounder) are less than those for the GI guns. It is assumed that, during simultaneous operations of the GI guns and other sound sources, any marine mammals close enough to be affected by the other sound sources would already be affected by the GI guns. However, whether or not the GI guns are operating simultaneously with the other sound sources, marine mammals are expected to exhibit no more than short-term and inconsequential responses to the other sound sources given their characteristics (e.g., narrow downward-directed beam in the echosounder) and other considerations described in § II and IV, above. Such reactions are not considered to constitute "taking" (NMFS 2001). Therefore, no additional allowance is included for animals that could be affected by the other sound sources.

(a) Basis for Estimating "Take by Harassment" for the 2009 MV Study

Extensive systematic aircraft- and ship-based surveys have been conducted for marine mammals offshore from New England (e.g., see Palka 2006). Those that were conducted in the proposed seismic survey area[3] were used for density estimates. Oceanographic conditions influence the distribution and

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[3] The abundance data in Palka (2006) are given by survey and location, according to U.S. Navy Operating Areas; the areas where the proposed seismic survey is planned (mostly Georges West, extending slightly into Georges Central and Shelf Central) were covered only by aerial surveys in 2002 and 2004.

numbers of marine mammals present in the study area, resulting in year-to-year variation in the distribution and abundance of many marine mammal species. Thus, for some species the densities derived from these surveys may not be representative of the densities that will be encountered during the proposed seismic survey. To provide some allowance for these uncertainties, "maximum estimates" as well as "best estimates" of the numbers potentially affected have been derived. Best and maximum estimates are based on the average and maximum[4] estimates of densities calculated from the appropriate densities reported by Palka (2006).

Table 10 gives the average and maximum densities for each species of cetacean reported in the proposed survey area off New England, corrected for effort, based on the densities as described above. The densities from those studies had been corrected, by the original authors, for both detectability bias and availability bias. Detectability bias is associated with diminishing sightability with increasing lateral distance from the trackline [$f(0)$]. Availability bias refers to the fact that there is less-than-100% probability of sighting an animal that is present along the survey trackline, and it is measured by $g(0)$.

It should be noted that the following estimates of "takes by harassment" assume that the surveys will be undertaken and completed. As is typical for offshore ship surveys, inclement weather and equipment malfunctions are likely to cause delays and may limit the number of useful line-kilometers of seismic operations that can be undertaken. Furthermore, any marine mammal sightings within or near the designated safety zones will result in the shut down of seismic operations as a mitigation measure. Thus, the following estimates of the numbers of marine mammals potentially exposed to 160- or 170-dB sounds are precautionary, and probably overestimate the actual numbers of marine mammals that might be involved. These estimates assume that there will be no weather, equipment, or mitigation delays, which is highly unlikely.

There is some uncertainty about how representative these data are and the assumptions used in the calculations below. However, the approach used here is believed to be the best available approach. As noted above, to provide some allowance for these uncertainties "maximum estimates" as well as "best estimates" of the numbers potentially affected have been derived. The estimated numbers of potential individuals exposed are presented below based on the 160-dB re 1 μPa_{rms} criterion for all cetaceans, and also based on the 170-dB criterion for delphinids only. It is assumed that a marine mammal exposed to airgun sounds this strong might change its behavior sufficiently to be considered "taken by harassment" (see § I and Table 1 for a discussion of the origin of these potential disturbance isopleths).

(b) Potential Number of "Takes by Harassment"

***Best and Maximum Estimates of the Number of Cetaceans that may be Exposed to ≥160 dB*.**— The number of different individuals that may be exposed to GI-gun sounds with received levels ≥160 dB re 1 μPa_{rms} on one or more occasions can be estimated by considering the total marine area that would be within the 160-dB radius around the operating GI guns on at least one occasion. The proposed seismic lines do not run parallel to each other in close proximity, which minimizes the number of times an individual mammal may be exposed during the survey; in this case, an individual could be exposed 1.13 times on average. Table 11 shows the best and maximum estimates of the number of marine mammals that could potentially be affected during the seismic survey.

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[4] Average density is the mean of the calculated densities for all strata (year-area combinations), weighted by survey effort in each stratum and the proportional # seismic survey km in each area, whereas maximum density is the highest calculated density in any stratum.

Table 10. Densities of marine mammals sighted during NMFS aerial surveys in the proposed survey area off MV during summer 2002 and 2004 (Palka 2006) with their approximate coefficients of variation (CV). Densities are corrected for *f*(0) and *g*(0). Species listed as "Endangered" under the ESA are in italics.

	Average Density (#/1000 km^2)		Maximum Density (#/1000 km^2)	
Species	**Density**	**CV** [a]	**Density**	**CV** [a]
Mysticetes				
Humpback whale	*0.56*	*0.60*	*19.68*	*0.65*
Minke whale	0.05	0.94	7.35	0.94
Fin whale	*3.86*	*0.68*	*26.09*	*0.76*
Odontocetes				
Sperm whale	*0.38*	*0.94*	*26.88*	*0.94*
Unidentified beaked whale	<0.01	N.A. [b]	0.82	N.A. [b]
Bottlenose dolphin	14.02	0.76	163.02	N.A. [b]
Striped dolphin	0.11	N.A. [b]	73.61	N.A. [b]
Common dolphin [c]	128.88	0.41	1108.71	0.05
Risso's dolphin	0.48	N.A. [b]	322.67	N.A. [b]
Pilot whale	6.44	0.52	382.52	0.52

[a] CV (Coefficient of Variation) is a measure of a number's variability. The larger the CV, the higher the variability. It is estimated by 0.94 - 0.162log$_e$n from Koski et al. (1998), but likely underestimates true variability.

[b] Not available. Sightings for one stratum (Shelf Center) not given.

[c] Not identified to species level.

The number of different individuals potentially exposed to ≥160 dB re 1 µPa$_{rms}$ was calculated by multiplying

- the expected species density, either "mean" (i.e., best estimate) or "maximum", times
- the anticipated area to be ensonified to that level during GI-gun operations.

The area expected to be ensonified was determined by entering the planned survey lines into a MapInfo Geographic Information System (GIS), using the GIS to identify the relevant areas by "drawing" the applicable 160-dB or 170-dB buffer (see Table 1) around each seismic line (2-gun buffer) and turn (1-gun buffer) and then calculating the total area within the buffers. Areas where overlap occurred (because of intersecting lines) were included only once to determine the minimum area expected to be ensonified.

Applying the approach described above, ~2877 km^2 would be within the 160-dB isopleth on one or more occasions during the survey. This approach does not allow for turnover in the mammal populations in the study area during the course of the studies. That might underestimate actual numbers of individuals exposed, although the conservative distances used to calculate the area may offset this. In addition, the approach assumes that no cetaceans will move away or toward the trackline as the *Endeavor* approaches in response to increasing sound levels prior to the time the levels reach 160 dB. Another way of interpreting the estimates that follow is that they represent the number of individuals that are expected (in the absence of a seismic program) to occur in the waters that will be exposed to ≥160 dB re 1 µPa$_{rms}$.

The 'best estimate' of the number of individual cetaceans that might be exposed to seismic sounds with received levels ≥160 dB re 1 µPa$_{rms}$ during the surveys is 416 (Table 11). That total includes 16 ***endangered*** whales (1 North Atlantic right, 2 humpback, 11 fin, and 2 sperm whales) and no beaked whales. The common dolphin and bottlenose dolphin are estimated to be the most common species

TABLE 11. Estimates of the possible numbers of marine mammals exposed to sound levels >160 and >170 dB during Rice's proposed seismic surveys off MV in August 2009. The proposed sound source is two 45-in^3 GI guns. Received levels of airgun sounds are expressed in dB re 1 µPa (rms, averaged over pulse duration). Not all marine mammals will change their behavior when exposed to these sound levels, but some may alter their behavior when levels are lower (see text). Delphinids are unlikely to react to levels below 170 dB. Species in italics are listed under the U.S. ESA as endangered. The column of numbers in boldface shows the numbers of "takes" for which authorization is requested.

	Number of Individuals Exposed to Sound Levels >160 dB (>170 dB, Delphinids)					
	Best Estimate[1]					
Species	**Number**		**% of Regional Pop'n[2]**	**Maximum Estimate[1]**		**Requested Take Authorization**
Balaenopteridae						
North Atlantic right whale [3]	*1*		0.31	*1*		***1***
Humpback whale	*2*		0.02	*57*		***2***
Minke whale	0		<0.01	21		**0**
Fin whale	*11*		0.03	*75*		***11***
Physeteridae						
Sperm whale	*2*		0.02	*77*		***2***
Ziphiidae						
Unidentified beaked whale	0		NA	2		**0**
Delphinidae						
Bottlenose dolphin	39	(21)	0.05	4700	(255)	**39**
Atlantic spotted dolphin [3]	0		0	0		**0**
Striped dolphin	0	(0)	<0.01	212	(115)	**0**
Common dolphin	349	(190)	0.17	3189	(1734)	**349**
Atlantic white-sided dolphin [3]	0		0	0	0	**0**
Risso's dolphin	2	(1)	0.01	929	(505)	**2**
Pilot whale	10	(6)	<0.01	1101	(599)	**10**
Phocidae						
Harbor seal[4]	10		0.01			**10**
Gray seal[4]	5		<0.01			**5**

[1] Best and maximum density estimates are primarily from Table 10 (see text).

[2] Regional population size estimates are from Table 3; NA means not available.

[3] Species not sighted in the surveys used for density estimates, but that could occur in low densities in the proposed survey area.

[4] Species for which summer densities in the study area are unavailable, but could occur there in low numbers.

exposed; the best estimates for those species are 372 and 40, respectively. Estimates for the other dolphin species that could be exposed are lower (Table 11). In addition, it is estimated that 15 pinnipeds may be exposed during the proposed study.

The 'Maximum Estimate' column in Table 11 shows an estimated total of 6134 cetaceans exposed to seismic sounds ≥160 dB during the surveys. Those estimates are based on the highest calculated density in any survey stratum; in this case, the stratum with the highest density invariably was one of the areas where very little of the proposed seismic survey will take place, i.e., Georges Central or Shelf Central. In other words, densities observed in the 2002 and 2004 aerial surveys were lowest in the Georges West operation area, where most of the proposed seismic surveys will take place. Therefore, the numbers for which "***take authorization***" is requested, given in the far right column of Table 11, are the best estimates. For three ***endangered*** species, the best estimates were set at the species' mean group size. The North Atlantic right whale, which was not sighted during the aerial surveys, could occur in the survey area, and is usually seen individually (feeding aggregations are not expected to occur in the study area). The humpback and sperm whales, each of whose calculated best estimate was 1, have a mean group size of 2.

Best and Maximum Estimates of the Number of Delphinids that might be Exposed to ≥170 dB.—The 160-dB criterion, on which the preceding estimates are based, was derived from studies of baleen whales. Odontocete hearing at low frequencies is relatively insensitive, and delphinids generally appear to be more tolerant of strong low-frequency sounds than are most baleen whales. As summarized in Appendix A (e), delphinids commonly occur within distances where received levels would be expected to exceed 160 dB re 1 μPa_{rms}. There is no generally accepted alternative "take" criterion for delphinids exposed to airgun sounds. However, our estimates assume that only those delphinids exposed to ≥170 dB re 1 μPa_{rms}, on average, would be affected sufficiently to be considered "taken by harassment". ("On average" means that some individuals might react significantly upon exposure to levels somewhat <170 dB, but others would not do so even upon exposure to levels somewhat >170 dB.) The area ensonified by levels ≥170 dB was determined (as described above for levels ≥160 dB) and was multiplied by the marine mammal density in order to obtain best and maximum estimates.

The best and maximum estimates of the numbers of exposures to ≥170 dB for all delphinids during the surveys are 217 and 3209, respectively (Table 11). The best estimates of the numbers of individuals that might be exposed to ≥170 dB for the three most abundant delphinid species are 190 common dolphins, 21 bottlenose dolphins, and 6 pilot whales. These values are based on the predicted 170-dB radii around the GI guns to be used during the study and are considered to be more realistic estimates of the number of individual delphinids that may be affected.

(d) Conclusions

The proposed survey off MV will involve towing two GI-guns that introduce pulsed sounds into the ocean, along with simultaneous operation of at least one of a sub-bottom profiler, an echosounder, or a boomer system. A towed hydrophone streamer will be deployed to receive and record the returning signals. Routine vessel operations, other than the proposed GI-gun operations, are conventionally assumed not to affect marine mammals sufficiently to constitute "taking". No "taking" of marine mammals is expected in association with operations of the other sound sources given the considerations discussed in § IV(1)(b), i.e., sounds are beamed downward, the beam is narrow, and the pulses are extremely short.

Cetaceans—Strong 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 when much larger airgun arrays have been used. However, reactions at the longer distances appear to be atypical of most species and situations and to the larger arrays. Furthermore, if they are encountered, the numbers of mysticetes estimated to occur within the 160-dB isopleth in the survey area are expected to be very low. In addition, the estimated numbers presented in Table 11 are considered overestimates of actual numbers because the estimated 160-and 170-dB radii used here are probably overestimates of the actual 160-and 170-dB radii at the deep-water locations in this study (Tolstoy et al. 2004a,b).

Odontocete reactions to seismic pulses, or at least the reactions of delphinids, are expected to extend to lesser distances than are those of mysticetes. Odontocete low-frequency hearing is less sensitive than that of mysticetes, and dolphins are often seen from seismic vessels. In fact, there are documented instances of dolphins approaching active seismic vessels. However, delphinids and some other types of odontocetes sometimes show avoidance responses and/or other changes in behavior when near operating seismic vessels.

Taking into account the mitigation measures that are planned (see § II), 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 very low percentages of the regional population sizes. The best estimate of the number of individual cetaceans (57 for all species combined) that would be exposed to sounds ≥160 dB re 1 $\mu\text{Pa}_{\text{rms}}$ during the proposed survey represent, on a species-by-species basis, no more than 0.19% of the regional populations (Table 11). Dolphins are the cetaceans with the highest estimated numbers exposed, but the population sizes of species likely to occur there are also large, and the numbers within the ≥160-dB zones are small relative to the population sizes (Table 11). Also, these delphinids are not expected to be disturbed appreciably at received levels below 170 dB re 1 $\mu\text{Pa}_{\text{rms}}$. The numbers of delphinids estimated to be exposed to sounds >170 dB during the proposed survey represent ≤0.10% of the population size of any of the species.

Varying estimates of the numbers of marine mammals that might be exposed to GI-gun sounds during the proposed seismic survey off New England have been presented, depending on the specific exposure criterion (≥160 or ≥170 dB) and density criterion used (best or maximum). The requested "take authorization" for each species is based on the estimated average numbers of individuals exposed to ≥160 dB re 1 $\mu\text{Pa}_{\text{rms}}$. That figure likely overestimates the actual number of animals that will be exposed to the seismic sounds; the reasons for that are outlined above. The relatively short-term exposures are unlikely to result in any long-term negative consequences for the individuals or their populations.

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 look outs, non-pursuit, and shut downs when marine mammals are seen within defined ranges should further reduce short-term reactions, and minimize any effects on hearing sensitivity. In all cases, the effects are expected to be short-term, with no lasting biological consequence.

Pinnipeds—An estimated 10 harbor seals and five gray seals may be exposed to airgun sounds during the proposed study. This estimate represents 0.01% or less of the regional populations.

Sea Turtles**—**There are no nesting sea turtles on the New England coast. It is possible that some sea turtles will be encountered during the project, but it is anticipated that the proposed seismic survey will have, at most, a short-term effect on behavior and no long-term impacts on individual sea turtles or their populations.

(4) Direct Effects on Fish and Their Significance

One reason for the adoption of airguns as the standard energy source for marine seismic surveys is that, unlike explosives, they have not been associated with large-scale fish kills. However, existing information on the impacts of seismic surveys on marine fish populations is very limited (see Appendix C). There are three types of potential effects of exposure to seismic surveys: (1) pathological, (2) physiological, and (3) behavioral. Pathological effects involve lethal and temporary or permanent sub-lethal injury. Physiological effects involve temporary and permanent primary and secondary stress responses, such as changes in levels of enzymes and proteins. Behavioral effects refer to temporary and (if they occur) permanent changes in exhibited behavior (e.g., startle and avoidance behavior). The three categories are interrelated in complex ways. For example, it is possible that certain physiological and behavioral changes could potentially lead to an ultimate pathological effect on individuals (i.e., mortality).

The specific received sound levels at which permanent adverse effects to fish potentially could occur are little studied and largely unknown. Furthermore, the available information on the impacts of seismic surveys on marine fish is from studies of individuals or portions of a population; there have been no studies at the population scale. Thus, available information provides limited insight on possible real-world effects at the ocean or population scale. This makes drawing conclusions about impacts on fish problematic because ultimately, the most important aspect of potential impacts relates to how exposure to seismic survey sound affects marine fish populations and their viability, including their availability to fisheries.

The following sections provide a general synopsis of available information on the effects of exposure to seismic and other anthropogenic sound as relevant to fish. The information comprises results from scientific studies of varying degrees of rigor plus some anecdotal information. Some of the data sources may have serious shortcomings in methods, analysis, interpretation, and reproducibility that must be considered when interpreting their results (see Hastings and Popper 2005). Potential adverse effects of the program's sound sources on marine fish are then noted.

Pathological Effects.—The potential for pathological damage to hearing structures in fish depends on the energy level of the received sound and the physiology and hearing capability of the species in question (see Appendix C). For a given sound to result in hearing loss, the sound must exceed, by some specific amount, the hearing threshold of the fish for that sound (Popper 2005). The consequences of temporary or permanent hearing loss in individual fish on a fish population is unknown; however, it likely depends on the number of individuals affected and whether critical behaviors involving sound (e.g. predator avoidance, prey capture, orientation and navigation, reproduction, etc.) are adversely affected.

Little is known about the mechanisms and characteristics of damage to fish that may be inflicted by exposure to seismic survey sounds. Few data have been presented in the peer-reviewed scientific literature. As far as we know, there are only two valid papers with proper experimental methods, controls, and careful pathological investigation implicating sounds produced by actual seismic survey airguns with adverse anatomical effects. One such study indicated anatomical damage and the second indicated TTS in fish hearing. The anatomical case is McCauley et al. (2003), who found that exposure to airgun sound caused observable anatomical damage to the auditory maculae of "pink snapper" (*Pagrus auratus*). This damage in the ears had not been repaired in fish sacrificed and examined almost two months after exposure. On the other hand, Popper et al. (2005) documented only TTS (as determined by auditory brainstem response) in two of three fishes from the Mackenzie River Delta. This study found that broad whitefish (*Coregonus nasus*) that received a sound exposure level of 177 dB re 1 $\mu Pa^2 \cdot s$ showed no hearing loss. During both studies, the repetitive exposure to sound was greater than would have occurred during a typical seismic survey. However, the substantial low-frequency energy produced by the airgun arrays [less than ~400 Hz in the study by McCauley et al. (2003) and less than ~200 Hz in Popper et al. (2005)] likely did not propagate to the fish because the water in the study areas was very shallow (~9 m in the former case and <2 m in the latter). Water depth sets a lower limit on the lowest sound frequency that will propagate (the "cutoff frequency") at about one-quarter wavelength (Urick 1983; Rogers and Cox 1988).

Except for these two studies, at least with airgun-generated sound treatments, most contributions rely on rather subjective assays such as fish "alarm" or "startle response" or changes in catch rates by fishers. These observations are important in that they attempt to use the levels of exposures that are likely to be encountered by most free-ranging fish in actual study areas. However, the associated sound stimuli are often poorly described, and the biological assays are varied (Hastings and Popper 2005).

Wardle et al. (2001) suggested that in water, acute injury and death of organisms exposed to seismic energy depends primarily on two features of the sound source: (1) the received peak pressure and (2) the time required for the pressure to rise and decay. Generally, as received pressure increases, the period for the pressure to rise and decay decreases, and the chance of acute pathological effects increases. According to Buchanan et al. (2004), for the types of seismic airguns and arrays involved with the proposed program, the pathological (mortality) zone for fish would be expected to be within a few meters of the seismic source. Numerous other studies provide examples of no fish mortality upon exposure to seismic sources (Falk and Lawrence 1973; Holliday et al. 1987; La Bella et al. 1996; Santulli et al. 1999; McCauley et al. 2000a,b, 2003; Bjarti 2002; Hassel et al. 2003; Popper et al. 2005).

Some studies have reported, some equivocally, that mortality of fish, fish eggs, or larvae can occur close to seismic sources (Kostyuchenko 1973; Dalen and Knutsen 1986; Booman et al. 1996; Dalen et al. 1996). Some of the reports claimed seismic effects from treatments quite different from actual seismic survey sounds or even reasonable surrogates. Saetre and Ona (1996) applied a ‘worst-case scenario’ mathematical model to investigate the effects of seismic energy on fish eggs and larvae. They concluded that mortality rates caused by exposure to seismic surveys are so low, as compared to natural mortality rates, that the impact of seismic surveying on recruitment to a fish stock must be regarded as insignificant.

Physiological Effects.—Physiological effects refer to cellular and/or biochemical responses of fish to acoustic stress. Such stress potentially could affect fish populations by increasing mortality or reducing reproductive success. Primary and secondary stress responses of fish after exposure to seismic survey sound appear to be temporary in all studies done to date (Sverdrup et al. 1994; McCauley et al. 2000a,b). The periods necessary for the biochemical changes to return to normal are variable, and depend on numerous aspects of the biology of the species and of the sound stimulus (see Appendix C).

Behavioral Effects.—Behavioral effects include changes in the distribution, migration, mating, and catchability of fish populations. Studies investigating the possible effects of sound (including seismic survey sound) on fish behavior have been conducted on both uncaged and caged individuals (Chapman and Hawkins 1969; Pearson et al. 1992; Santulli et al. 1999; Wardle et al. 2001; Hassel et al. 2003). Typically, in these studies fish exhibited a sharp “startle” response at the onset of a sound followed by habituation and a return to normal behavior after the sound ceased.

There is general concern about potential adverse effects of seismic operations on fisheries, namely a potential reduction in the “catchability” of fish involved in fisheries. Although reduced catch rates have been observed in some marine fisheries during seismic testing, in a number of cases the findings are confounded by other sources of disturbance (Dalen and Raknes 1985; Dalen and Knutsen 1986; Løkkeborg 1991; Skalski et al. 1992; Engås et al. 1996). In other airgun experiments, there was no change in catch per unit effort (CPUE) of fish when airgun pulses were emitted, particularly in the immediate vicinity of the seismic survey (Pickett et al. 1994; La Bella et al. 1996). For some species, reductions in catch may have resulted from a change in behavior of the fish, e.g., a change in vertical or horizontal distribution, as reported in Slotte et al. (2004).

In general, any adverse effects on fish behavior or fisheries attributable to seismic pulses may depend on the species in question and the nature of the fishery (season, duration, fishing method). They may also depend on the age of the fish, its motivational state, its size, and numerous other factors that are difficult, if not impossible, to quantify at this point, given such limited data on effects of airguns on fish, particularly under realistic at-sea conditions.

(5) Direct Effects on Invertebrates and Their Significance

The existing body of information on the impacts of seismic survey sound on marine invertebrates is very limited. However, there is some unpublished and very limited evidence of the potential for adverse effects on invertebrates, thereby justifying further discussion and analysis of this issue. The three types of potential effects of exposure to seismic surveys on marine invertebrates are pathological, physiological, and behavioral. Based on the physical structure of their sensory organs, marine invertebrates appear to be specialized to respond to particle displacement components of an impinging sound field and not to the pressure component (Popper et al. 2001; see also Appendix D).

The only information available on the impacts of seismic surveys on marine invertebrates involves studies of individuals; there have been no studies at the population scale. Thus, available information provides limited insight on possible real-world effects at the regional or ocean scale. The most important aspect of potential impacts concerns how exposure to seismic survey sound ultimately affects invertebrate populations and their viability, including availability to fisheries.

The following sections provide a synopsis of available information on the effects of exposure to seismic survey sound on species of decapod crustaceans and cephalopods, the two taxonomic groups of invertebrates on which most such studies have been conducted. The available information is from studies with variable degrees of scientific soundness and from anecdotal information. A more detailed review of the literature on the effects of seismic survey sound on invertebrates is provided in Appendix D.

Pathological Effects.—In water, lethal and sub-lethal injury to organisms exposed to seismic survey sound could depend on at least two features of the sound source: (1) the received peak pressure, and (2) the time required for the pressure to rise and decay. Generally, as received pressure increases, the period for the pressure to rise and decay decreases, and the chance of acute pathological effects increases. For the type of airgun array planned for the proposed program, the pathological (mortality) zone for crustaceans and cephalopods is expected to be within a few meters of the seismic source; however, very few specific data are available on levels of seismic signals that might damage these animals. This premise is based on the peak pressure and rise/decay time characteristics of seismic airgun arrays currently in use around the world.

Some studies have suggested that seismic survey sound has a limited pathological impact on early developmental stages of crustaceans (Pearson et al. 1994; Christian et al. 2003; DFO 2004). However, the impacts appear to be either temporary or insignificant compared to what occurs under natural conditions. Controlled field experiments on adult crustaceans (Christian et al. 2003, 2004; DFO 2004) and adult cephalopods (McCauley et al. 2000a,b) exposed to seismic survey sound have not resulted in any significant pathological impacts on the animals. It has been suggested that exposure to commercial seismic survey activities has injured giant squid (Guerra et al. 2004), but there is no evidence to support such claims.

Physiological Effects.—Physiological effects refer mainly to biochemical responses by marine invertebrates to acoustic stress. Such stress potentially could affect invertebrate populations by increasing mortality or reducing reproductive success. Any primary and secondary stress responses (i.e., changes in haemolymph levels of enzymes, proteins, etc.) of crustaceans after exposure to seismic survey sounds appear to be temporary (hours to days) in studies done to date (J. Payne, Department of Fisheries and Oceans [DFO] research scientist, St. John's, NL, Canada, pers. comm.). The periods necessary for these biochemical changes to return to normal are variable and depend on numerous aspects of the biology of the species and of the sound stimulus.

Behavioral Effects.—There is increasing interest in assessing the possible direct and indirect effects of seismic and other sounds on invertebrate behavior, particularly in relation to the consequences for fisheries. Changes in behavior could potentially affect such aspects as reproductive success, distribution, susceptibility to predation, and catchability by fisheries. Studies investigating the possible behavioral effects of exposure to seismic survey sound on crustaceans and cephalopods have been conducted on both uncaged and caged animals. In some cases, invertebrates exhibited startle responses (e.g., squid in McCauley et al. 2000a,b). In other cases, no behavioral impacts were noted (e.g., crustaceans in Christian et al. 2003, 2004; DFO 2004). There have been anecdotal reports of reduced catch rates of shrimp shortly after exposure to seismic surveys; however, other studies have not observed any significant changes in shrimp catch rate (Andriguetto-Filho et al. 2005). Any adverse effects on crustacean and cephalopod behavior or fisheries attributable to seismic survey sound depend on the species in question and the nature of the fishery (season, duration, fishing method).

(6) Direct Effects on EFH and HAPC

Seismic sound should not have any direct effect on EFH, given that the definition of EFH includes only chemical and physical criteria, not biological criteria (e.g., prey species). The proposed GI gun operations will not result in any impact on HAPC, either the physical substrate or marine vegetation; there are no known effects of sound on algae or sea grass.

(7) Direct Effects on Seabirds and Their Significance

Investigations into the effects of airguns on seabirds are extremely limited. Stemp (1985) conducted opportunistic observations on the effects of seismic exploration on seabirds, and Lacroix et al. (2003) investigated the effect of seismic surveys on molting long-tailed ducks in the Beaufort Sea, Alaska. Stemp (1985) did not observe any effects of seismic testing, although he warned that his observations should not be extrapolated to areas with large concentrations of feeding or molting birds. In a more intensive and directed study, Lacroix et al. (2003) did not detect any effects of nearshore seismic exploration on molting long-tailed ducks in the inshore lagoon systems of Alaska’s North Slope. Both aerial surveys and radio-tracking indicated that the proportion of ducks that stayed near their marking location from before to after seismic exploration was unaffected by proximity to seismic survey activities. Seismic activity also did not appear to change the diving intensity of long-tailed ducks significantly.

Birds might be affected slightly by seismic sounds from the proposed study, but the impacts are not expected to be significant to individual birds or their populations. The types of impacts that are possible are summarized below:

Localized, temporary displacement and disruption of feeding.—Such displacements would be similar to those caused by other large vessels that passed through the area. Any adverse effects would be negligible.

Modified prey abundance.—It is unlikely that prey species for birds will be affected by seismic activities to a degree that affects the foraging success of birds. If prey species exhibit avoidance of the ship, the avoidance is expected to be transitory and limited to a very small portion of a bird’s foraging range.

Disturbance to breeding birds.—A vessel (seismic or otherwise) that approaches too close to a breeding colony could disturb adult birds from nests in response either to sonic or to visual stimuli. There is limited potential for this because the seismic vessel will be close to shore (~1.4 km) only at the inner ends of survey lines near MV (see Fig. 1), and only for very short periods of time. The closest established breeding colony for roseate terns is found on Bird Island several kilometer away in Buzzards Bay, MA

Egg and nestling mortality.—Disturbance of adult birds from nests can lead to egg or nestling mortality *via* temperature stress or predation. There is limited potential for this considering the distance that the seismic survey will occur from major colonies, including Bird Island.

Chance injury or mortality.—Many species of marine birds feed by diving to depths of several meters or more. Flocks of feeding birds may consist of hundreds or even thousands of individuals. Also, some species of seabirds (particularly alcids) escape from boats by diving when the boat gets too close. It is possible that, during the course of normal feeding or escape behavior, some birds could be near enough to an airgun to be injured by a pulse. Although no specific information is available about the circumstances (if any) where this might occur, the negligible aversive reactions of birds to airguns (see above) suggest that a bird would have to be very close to any airgun to receive a pulse with sufficient energy to cause injury, if that is possible at all.

Induced injury or mortality.—If it disorients, injures, or kills prey species, or otherwise increases the availability of prey species to marine birds, a seismic survey could attract birds. Birds drawn too close to an airgun may be at risk of injury. However, available evidence from other seismic surveys utilizing airguns has not shown a pattern of fish (or other prey) kills from airguns [see § IV(5), above]. Thus, the potential that birds would be attracted and subsequently injured by the proposed seismic survey appears very low.

(8) Indirect Effects on Marine Mammals, Sea Turtles, and Their Significance

The proposed GI gun operations will not result in any permanent impact on habitats used by marine mammals or sea turtles, or to the food sources they use. The main impact issue associated with the proposed activities will be temporarily elevated noise levels and the associated direct effects on marine mammals and sea turtles, as discussed above.

During the seismic study, only a small fraction of the available habitat would be ensonified at any given time. Disturbance to fish species and invertebrates would be short-term, and fish would return to their pre-disturbance behavior once the seismic activity ceased [see § IV(5) and § IV(6), above]. Thus, the proposed survey would have little impact on the abilities of marine mammals or sea turtles to feed in the area where seismic work is planned.

Some mysticetes feed on concentrations of zooplankton. A reaction by zooplankton to a seismic impulse would only be relevant to whales if it caused a concentration of zooplankton to scatter. Pressure changes of sufficient magnitude to cause that type of reaction would probably occur only very close to the source. Impacts on zooplankton behavior are predicted to be negligible, and that would translate into negligible impacts on those mysticetes that feed on zooplankton.

(9) Cumulative Effects

Cumulative effects refer to the impacts on the environment that result from a combination of past, existing, and reasonably foreseeable projects and human activities. Causal agents of cumulative effects can include multiple causes, multiple effects, effects of activities in more than one locale, and recurring events. Human activities in the region of the proposed seismic survey in Nantucket Sound and south of MV and Nantucket include commercial and recreational vessel traffic, fishing, and coastal development associated with tourism. Those activities, when conducted separately or in combination with other activities, could affect marine mammals and sea turtles in the proposed study area.

(a) Shipping, Tourism, and Vessel Noise

Vessel noise could affect marine animals in the proposed study area. Shipping noise generally dominates ambient noise at frequencies from 20 to 300 Hz (Richardson et al. 1995). Baleen whales are thought to be more sensitive to sound at these low frequencies than are toothed whales. There may be some localized avoidance by marine mammals of commercial ships operating routinely in and near the proposed seismic study area. However, some species (e.g., North Atlantic right whales) apparently show little avoidance of shipping vessels in this region. Vessel traffic in the proposed study area will consist of fishing vessels, as well as other commercial (cargo), cruise, and pleasure vessels.

The proposed study area is adjacent to some of the busiest shipping routes in the U.S. A total of 295 million tons of waterborne cargo were handled at ports in Massachusetts, Rhode Island, Connecticut, New York, and New Jersey in 2006, including exports, imports, and intrastate shipments (WCS 2009). New Jersey and New York recorded the highest waterborne tonnage at 135 and 102 million tons, respectively (WCS 2009). Of the 150 busiest U.S. ports by waterborne tonnage in 2006 (WCS 2009), 13 are between Massachusetts and New Jersey: New York, New York/NJ (3rd), Paulsboro, NJ (19th), Boston, MA (37th), New Haven, CT (51st), Providence, RI (56th), Camden-Gloucester, NJ (65th), Albany, NY (62nd), Bridgeport, CT (76th), Fall River, MA (98th), Trenton, NJ (136th), Hempstead, NY (139th), Salem, MA (145th), and Port Jefferson, NY (150th). The shipping lanes off the U.S. Atlantic coast are oriented in north-south and east-west directions (Gaines et al. 1987). The north-south vessel traffic (Fig. 4a) is predominately domestic commercial shipping activity and occurs along the entire eastern coastline in inshore (<200 m depth) and offshore (200–2000 m depth) waters. The more variable U.S.-Caribbean and transatlantic shipping lanes (Figs. 4b and 4c, respectively) are mainly dictated by the vessel's final destination. Several voluntary and required regulations now exist to limit the risk of North Atlantic right whale ship strikes, including speed restrictions, re-direction of shipping lanes, and vessel contacts with shore-based stations (see below).

Tourism is an important industry for the states adjacent to the proposed study area. For example, tourism is the third largest industry in Massachusetts, with a total economic contribution to its economy exceeding $14.2 billion in 2006 (MOTT 2009). An estimated 21 million domestic visitors and 1.7 million international visitors came to Massachusetts in 2006 (MOTT 2009). The tourism industry supported 125,800 full-time, part-time, and seasonal jobs. The majority of domestic visitors traveled to the state by car (69%) and airplane (17%); ~250,000 domestic visitors traveled to the state via ship or boat (MOTT 2009).

Cape Cod and the islands of Martha's Vineyard and Nantucket receive a large percentage of their revenue from the tourism industry. An estimated six million visitors travel to Cape Cod annually, with the majority (nearly $^2/_3$) arriving typically from April through October (MMS 2009). Visitors are attracted to the area's high quality recreational activities, including many marine-based activities. In Nantucket Sound, recreational marine activities include fishing, sailing, cruising, boat racing, jet skiing, kayaking, and canoeing. All types of recreational watercraft from the smallest runabout to very large yachts and sailboats can be encountered in Nantucket Sound. The majority of the recreational activity occurs in coastal areas, but the larger power boats and sailboats can range into offshore waters. The recreational activities are often conducted in waters shared by commercial vessels, such as passenger ferries, barges carrying liquid and dry bulk goods, commercial and charter fishing boats, research vessels, and the occasional cruise ship. Recreational scuba diving is also common in New England waters, focused primarily on wreck diving or spearfishing. Many popular dive sites are located in waters <40 m deep and accessible directly from Massachusetts and New Jersey beaches or small boats (DoN 2005).

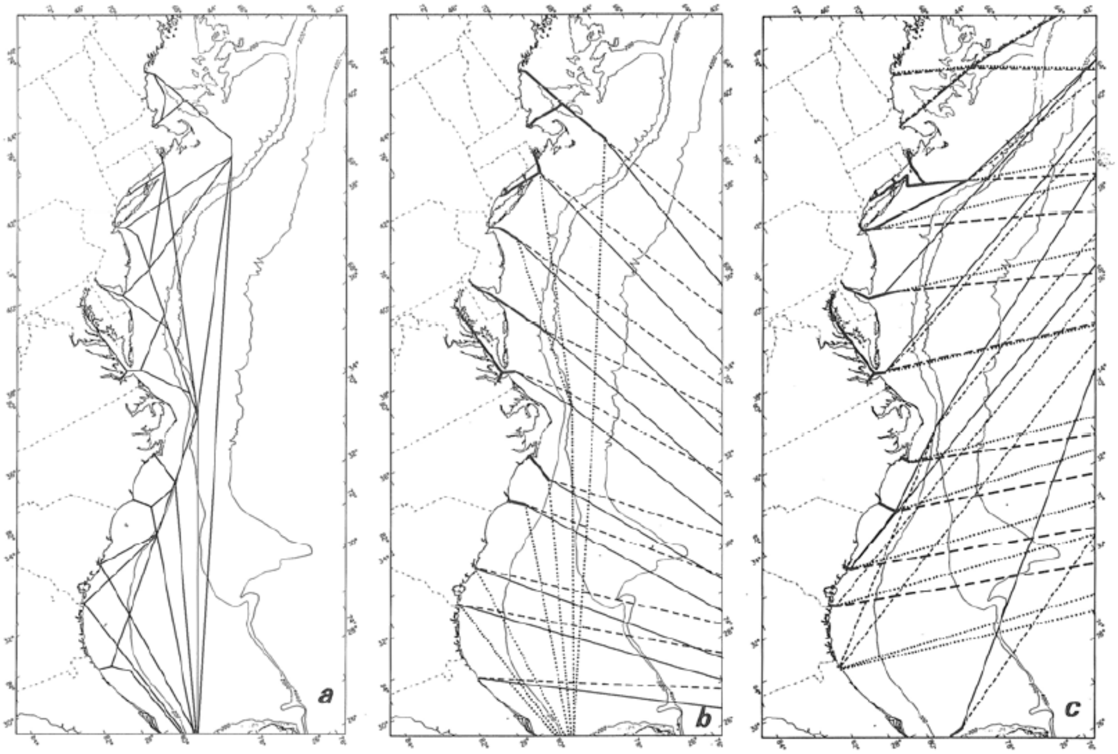

FIGURE 4. Shipping lanes along the U.S. eastern coastline for (a) domestic, (b) U.S.-Caribbean, and (c) transatlantic shipping (from Gaines et al. 1987).

The Steamship Authority (SA) provides year-round ferry service to the islands of Martha's Vineyard and Nantucket across Nantucket Sound. The SA currently operates seven vessels. From 1999 to 2008, the SA carried an annual average of ~2.8 million passengers, 475,000 vehicles, and 125,000 commercial freight trucks. Passenger and vehicle traffic generally peak in July and August, but commercial freight traffic peaks in May and June (SA 2009). From late June to early September, there are up to 15 roundtrip passages between Woods Hole and two ports on MV, and up to 11 roundtrip passages between Hyannis and Nantucket, including "fast ferry" trips (SA 2009). Other passenger ferries servicing the islands of Martha's Vineyard and Nantucket originate from Cape Cod, Rhode Island, and New York (MMS 2009).

Many visitors to Massachusetts engage in whale watching and other wildlife viewing cruises in coastal waters. In New England, there are at least 36 whale watch operators, including nine communities, 17 operators, and 30–35 vessels specifically in Massachusetts (Hoyt 2001). Many trips originate from Gloucester and several towns along the Cape Cod coast, including Provincetown, Hyannis, and Plymouth. Many operators make multiple trips per day, with each trip lasting 1.5−4 h. Whale watching tours are generally focused within 40 km of shore, and operate from April through October (MOTT 2009); Stellwagen Bank is often the primary destination of tours that primarily seek humpback whales.

Reactions of humpback whales to vessels have been studied, but there is limited information available about the reactions of right whales and rorquals (fin, blue and minke whales). Reactions of humpback whales to boats are variable, ranging from approach to avoidance (Payne 1978; Salden 1993). In southeast Alaska, concern was raised that increasing vessel traffic in Glacier Bay National Park may have caused humpbacks to leave the bay, particularly early in 1978 (Jurasz and Jurasz 1979). A subsequent detailed study confirmed that humpbacks often move away when vessels are within several km (Baker et al. 1982, 1983; Baker and Herman 1989), although reactions of humpbacks vary considerably. Humpbacks seem less likely to react overtly when actively feeding than when resting or engaged in other activities (Krieger and Wing 1984, 1986). North Atlantic right whales apparently show no response to playbacks of shipping sounds or actual shipping vessels, but react to a signal designed to alert whales to vessels by swimming to the surface (Nowacek et al. 2003).

Many odontocetes show considerable tolerance of vessel traffic, although they sometimes react at long distances if confined by ice or shallow water, or if previously harassed by vessels (Richardson et al. 1995). Dolphins of many species tolerate or even approach vessels. Some dolphin species approach moving vessels to ride the bow or stern waves (Williams et al. 1992). In western Australia, bottlenose dolphin behaviour became more erratic and dolphin schools tightened in response to controlled boat interactions (Bejder et al. 2006). During vessel interactions with bottlenose dolphins in New Zealand, travelling behavior increased and resting behavior decreased (Lusseau 2003, 2004). Additionally, dolphins apparently avoided areas and times characterized by high vessel traffic (Lusseau 2005). Common dolphins in New Zealand have also reacted to boats with changes in their overall behavioral budget, including decreases in foraging and resting times and increases in socializing and milling behaviors (Stockin et al. 2008). Killer whales rarely showed avoidance to boats within 400 m (Duffus and Dearden 1993), but when more than one boat was nearby, the whales swam faster and moved toward less confined waters (Kruse 1991). Killer whales have also been shown to increase travelling and decrease foraging behavior because of the presence of nearby vessels (Williams et al. 2002). Sperm whales often can be approached with small motorized or sailing vessels (Papastavrou et al. 1989), but they avoided outboard-powered whale watching vessels up to 2 km away (J. McGibbon *in* Cawthorn 1992). Thus, cetacean reactions to vessels are varied and range from approach to avoidance; some researchers suggest that vessel disturbances can lead to biologically-significant effects with long-term consequences for individuals or populations (see Lusseau and Bejder 2007) and urge that management schemes be established for populations with multiple potential stressors (e.g., Higham et al. 2009).

Ship strikes of baleen whales in New England waters may pose a significant impact to cetaceans, particularly to endangered baleen whales. As the speed and numbers of ships transiting marine waters has increased through time, so have the instances of collision between ships and cetaceans; 11 species are known to be hit by ships, with fin whales being most frequently struck, but right, humpback, sperm, and gray whales are also regularly hit (Laist et al. 2001). There are less frequent records of collisions with blue, sei, and minke whales (Laist et al. 2001). Collisions with ships travelling at speeds above 14 kt are expected to result in critical injury for right whales (Laist et al. 2001).

Death and major injury induced by ship strikes is one of the primary factors limiting the recovery of North Atlantic right whales, with nearly 36% of recorded deaths from 1970 to 1999 attributed to ship strikes (Knowlton and Kraus 2001). As noted earlier, North Atlantic right whales apparently show no response to vessel sounds, but swim to the surface in response to signals designed to alert whales of vessels; however, this response likely increases a whale's likelihood of collision (Nowacek et al. 2003). Monitoring of ship traffic and speeds in North Atlantic Right Whale Critical Habitat Areas during 1999–2002 suggested that ships were travelling averages of ~14.3 and ~15.7 kt in northern and southern habitat areas, respectively, and that the majority (69%) of ships transited northern habitat areas (Ward-Geiger et al. 2005). Several voluntary and mandatory regulations are now in place to reduce the risk of right whale collisions. Commercial ships must now report to shore-based stations when entering designated right whale critical habitat areas to receive information on reducing right whale collision, voluntary recommended shipping routes have been proposed for lanes that intersect critical habitat areas, and speeds of vessels >19.8 m (65 ft) are restricted to <10 kt in particular seasonal management areas (NMFS 2008b).

Additional information on these relatively new regulations are provided in § III. In Canadian waters, it was also recommended that shipping lanes be moved to avoid concentrations of right whales near Roseway Basin and in the Bay of Fundy (RWRT 2000). In the Bay of Fundy, the shipping lane has been moved to avoid the main concentration area of right whales near Grand Manan (Transport Canada 2003). The Roseway Basin is also an area recommended to be avoided seasonally by vessels >300 gross tonnes (IMO 2007).

The total transit distance by the *Endeavor* (~1757 km, including turns) will be minimal relative to total transit length for all cargo, cruise, and recreational vessels operating along the northeast U.S. Atlantic coast. As previously discussed, Rice's airgun operations will not cause any large-scale or prolonged effects. Thus, the combination of Rice's operations with the existing shipping and marine tourism operations is expected to produce only a negligible increase in overall ship disturbance effects on marine mammals. Rice's activities are not expected to have any significant impact on the wildlife viewing activities in the area.

(b) Fisheries

The primary contributions of fishing to potential cumulative impacts on marine mammals and sea turtles involve noise, potential entanglement, and the direct and indirect removal of prey items. There may be some localized avoidance by marine mammals of fishing vessels near the seismic area. Also, entanglement in fishing gear can lead to mortality of some marine mammals and sea turtles.

The waters off Massachusetts support many active fisheries. Most fishing occurs in coastal areas and in continental shelf and slope waters. Principal finfish fisheries are commercially directed at Atlantic mackerel, Atlantic herring, Atlantic cod, goosefish, skates, and silver hake. Important fisheries for squid, clams, scallops, and lobster also occur in the area. In addition, there are substantial recreational fisheries that target species in coastal and offshore waters (see further in § III).

Based on data from stock assessment reports required by the MMPA, the mean annual marine mammal bycatch by U.S. fisheries was estimated as 6215 individuals from 1990 to 1999 (Read et al. 2006). The majority of marine mammals (91%) were incidentally captured during gillnet fisheries, followed by trawl (5%), and other gear (4%), such as longlines, purse seines, and traps. In the Atlantic Ocean (including the Gulf of Mexico), U.S. fisheries incidentally harvested an average of 2577 cetaceans and 1038 pinnipeds annually over the ten-year period (Read et al. 2006). Marine mammal strandings and human-induced interaction events involving cetaceans are reported to the NMFS Northeast and Southeast Regional Offices by members of the National Stranding Network, large whale disentanglement teams, the U.S. Coast Guard, and civilian resources (Glass et al. 2008). The implementation of conservation measures during the early 1990s was effective in reducing marine mammal bycatch in U.S. fisheries, as indicated by a 40% decrease between 1990 and 1999. A portion of the decrease was also attributed to reduced fishing effort resulting from the collapse of important fish stocks, particularly in New England, during the early 1990s (Read et al. 2006). From 2002 to 2006, 469 unique events involving large cetaceans, such as right, humpback, fin, sei, blue, minke, and Bryde's whales, were reported along the eastern U.S. seaboard and adjacent Canadian Maritimes. Included in these events were 145 confirmed entanglements, 43 ship strikes, and 314 mortalities. Humpbacks (n = 77) were the most common large cetacean involved in entanglements, followed by minke (27, including nine mortalities) and right whales (25). Right whales (17), humpbacks (9), and fin whales (8) were the species most often involved in ship strikes. The reported numbers represent minimum values for human-induced serious injury and mortality for large cetaceans along the eastern seaboard (Glass et al. 2008). For example, humpback whale scar evidence suggested that only 3–10% of entanglements are witnessed and reported (Robbins and Mattila 2000, 2004).

Section 118 of the MMPA requires all commercial fisheries to be placed in one of three categories based on the level of incidental take of marine mammals relative to the Potential Biological Removal (PBR) for each marine mammal stock. Category I, II, and III fisheries are those for which the combined take is ≥50%, 1%–50%, and <1%, respectively, of PBR for a particular stock. Three Category I fisheries listed for 2009 have distributions that include the proposed study area (73 FR 73065-73066). The Category I fisheries, with number of marine mammal species or stocks incidentally killed or injured during commercial operations in parentheses, are the Atlantic Ocean large pelagics longline fishery (17), the northeast sink gillnet fishery (13), and the northeast American lobster trap and pot fishery (5). A further six fisheries are listed as Category II fisheries (73 FR 73066-73068): the northeast anchored float gillnet fishery (3), the northeast drift gillnet fishery (not documented), the northeast mid-water trawl (including paired trawl) fishery (4), the northeast bottom trawl fishery (6), the Atlantic blue crab trap and pot fishery (2), and the Atlantic mixed species trap and pot fishery (2). The remaining fisheries within the proposed survey area are listed as Category III or have no listing (73 FR 73068-73070).

(c) Summary of Cumulative Impacts to Marine Mammals

Impacts of Rice's proposed seismic survey off the Northeast U.S. Atlantic coast are expected to be no more than a very minor (and short-term) increment when viewed in light of other human activities within the study area. Unlike some other ongoing and routine activities (e.g., fishing), Rice's activities are not expected to result in injuries or deaths of marine mammals. Although the GI gun sounds from the seismic survey will have higher source levels than do the sounds from most other human activities in the area, GI-gun operation will be intermittent during the ~14-day program, in contrast to those from many other sources (mainly vessels) that have lower peak pressures but occur continuously over extended periods.

(d) Cumulative Impacts to Sea Turtles

Major threats to sea turtles include hunting and poaching, the collection of eggs, coastal development, increased tourism including beaches obstructed with lights and chairs, beach sand mining, pedestrian traffic, oil spills, ship strikes, entanglement in fishing gear, ingestion of plastic and marine garbage, and destruction of feeding habitat in coral reefs and seagrass beds (Horrocks 1992; Marcovaldi et al. 2003). Because the proposed study area is not near any sea turtle nesting sites, the seismic survey will not contribute to cumulative impacts at nesting sites. The survey will also not contribute substantially to the other cumulative impacts listed above; at most, relatively few numbers of non-breeding turtles could be disturbed, but there are no anticipated injurious or lethal effects at the individual or population levels.

(10) Unavoidable Impacts

Unavoidable impacts to the species of marine mammals and turtles occurring in the proposed study area will be limited to short-term, localized changes in behavior of individuals. For cetaceans, some of the changes in behavior may be sufficient to fall within the MMPA definition of "Level B Harassment" (behavioral disturbance; no serious injury or mortality). No long-term or significant impacts are expected on any of these individual marine mammals or turtles, or on the populations to which they belong. Effects on recruitment or survival are expected to be (at most) negligible.

(11) Coordination with Other Agencies and Processes

This EA will be used by NSF to comply with NEPA and by Rice in support of their request for an IHA to be issued by NMFS to authorize, under the U.S. MMPA, "taking by harassment" (disturbance) of small numbers of marine mammals during Rice's planned activities during the proposed seismic project in the NWA. Rice and NSF will coordinate the planned marine mammal monitoring program associated with the seismic survey off MV with other parties that may have interest in this area. NSF will coordinate with NMFS regarding ESA, EFH and HAPC, and the State of Massachusetts regarding the Coastal Zone Management Act.

Alternative Action: Another Time

An alternative to issuing the IHA for the period requested, and to conducting the project then, is to issue the IHA for another time, and to conduct the project at that alternative time. The proposed dates for the cruise (12–25 August 2009) are the dates when the personnel and equipment essential to meet the overall project objectives are available.

Marine mammals are expected to occur throughout the study area and time period during which the project is planned to occur. Some species are year-round residents in the NWA and would regularly be observed in Massachusetts waters (e.g., fin whale, common dolphin); thus, altering the timing of the proposed project likely would result in no net benefits for those species (see § III, above). A number of species are most common off New England in summer (sperm and beaked whales, and bottlenose, spotted, striped, and Risso's dolphins) but occur almost exclusively beyond the shelf break, whereas the survey is mostly on the shelf. Other species move north in summer to feed in waters off northern Maine and Canada (e.g., North Atlantic right, sei, and humpback whales, white-beaked and Atlantic white-sided dolphins, harbor porpoises, and harbor and gray seals), and conducting the survey in summer lessens potential effects on those species. Even though rescheduling the proposed project to a different time of the year may reduce or avoid some marine mammal species, numbers of other marine mammal species in the area would increase.

No Action Alternative

An alternative to conducting the proposed activities is the "No Action" alternative, i.e. do not issue an IHA and do not conduct the operations. If the research were not conducted, the "No Action" alternative would result in no disturbance to marine mammals or sea turtles attributable to the proposed activities.

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APPENDIX A:

REVIEW OF THE EFFECTS OF AIRGUN SOUNDS ON MARINE MAMMALS[5]

The following subsections review relevant information concerning the potential effects of 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. Categories of Noise Effects

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

1. The noise may be too weak to be heard at the location of the animal, i.e., lower than the prevailing ambient noise level, the hearing threshold of the animal at relevant frequencies, or both;
2. The noise may be audible but not strong enough to elicit any overt behavioral response, i.e., the mammal may tolerate it;
3. The noise 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 perceives as a threat;
5. Any man-made noise 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 such as surf noise or (at high latitudes) ice noise. However, intermittent airgun or sonar pulses could cause strong masking for only a small proportion of the time, given the short duration of these pulses relative to the inter-pulse intervals;
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.

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).

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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).

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 Gervais' beaked whale showed evoked potentials from 5 kHz up to 80 kHz (the entire frequency range that was tested), with the best sensitivity at 40–80 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).

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 contain 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 kilometers (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 kilometers.

2.2 Baleen Whales (Mysticetes)

The hearing abilities of baleen whales (mysticetes) have not been studied directly. 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 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 humpbacks, with components 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). For baleen whales as a group, the functional hearing range is thought to be about 7 Hz to 22 kHz and they constitute the "low-frequency" (LF) hearing group (Southall et al. 2007). 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. 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 seismic (or other source) sounds 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).

2.3 Seals and Sea Lions (Pinnipeds)

Underwater audiograms have been obtained using behavioral methods for three 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). 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 a harbor seal indicate that, below 1 kHz, its thresholds deteriorate gradually to ~97 dB re 1 µPa at 100 Hz (Kastak and Schusterman 1998).

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).

2.4 Manatees and Dugong (Sirenians)

The West Indian manatee can apparently detect sounds from 15 Hz to 46 kHz, based on a study involving behavioral testing methods (Gerstein et al. 1999). Thus, manatees may hear, or at least detect, sounds in the low-frequency range where most seismic energy is released. It is possible that they are able to feel these low-frequency sounds using vibrotactile receptors or because of resonance in body cavities or bone conduction.

Based on measurements of evoked potentials, manatee hearing is apparently best around 1–1.5 kHz (Bullock et al. 1982). However, behavioral testing suggests their best sensitivity is at 6–20 kHz (Gerstein et al. 1999). The ability to detect high frequencies may be an adaptation to shallow water, where the propagation of low frequency sound is limited (Gerstein et al. 1999).

2.5 Sea Otter and Polar Bear

No data are available on the hearing abilities of sea otters (Ketten 1998), although the in-air vocalizations of sea otters have most of their energy concentrated at 3–5 kHz (McShane et al. 1995; Thomson and Richardson 1995). Sea otter vocalizations are considered to be most suitable for short-range communication among individuals (McShane et al. 1995). In-air audiograms for two river otters indicate that this related species has its best hearing sensitivity at the relatively high frequency of 16 kHz, with some sensitivity from about 460 Hz to 33 kHz (Gunn 1988). However, these data apply to a different species of otter, and to in-air rather than underwater hearing.

Data on the specific hearing capabilities of polar bears are limited. A recent study of the in-air hearing of polar bears applied the auditory evoked potential method while tone pips were played to anesthetized bears (Nachtigall et al. 2007). Hearing was tested in ½ octave steps from 1 to 22.5 kHz, and best hearing sensitivity was found between 11.2 and 22.5 kHz. Although low-frequency hearing was not studied, the data suggested that medium- and some high-frequency sounds may be audible to polar bears. However, polar bears' usual behavior (e.g., remaining on the ice, at the water surface, or on land) reduces or avoids their exposure to underwater sounds.

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 firing 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 (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 20-airgun arrays used by Lamont-Doherty Earth Observatory (L-DEO) from the R/V *Maurice Ewing* during previous projects ranged from 236 to 263 dB re 1 μPa_{p-p}, considering the frequency band up to ~250 Hz. The source level for the largest airgun array deployed from the R/V *Marcus G. Langseth* (36 airguns) is 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. The only man-made sources with effective source levels as high as (or higher than) a large array of airguns are explosions and high-power sonars operating near maximum power.

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 seismic 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-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 quoted source or received levels. Geophysicists usually quote peak-to-peak (p-p) levels, in bar-meters or (less often) dB re 1 μPa · m. The peak (= zero-to-peak, or 0-p) level for the same pulse is typically ~6 dB less. In the biological 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). A fourth measure that is increasingly used is the energy, or 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.[6] 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 any quoted pulse level. In the past, 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 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 a seismic 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

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[6] 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 (MacGillivray and Hannay 2007a,b).

effects are more directly related to the received energy (e.g., to SEL) than to the rms values averaged over pulse duration (Southall et al. 2007).

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 kilometers 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).

4. Masking Effects of Airgun Sounds

Masking is the obscuring of sounds of interest by interfering sounds, generally at similar frequencies (Richardson et al. 1995). 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). 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. 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 might cause appreciable 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.

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. 1999; Nieukirk et al. 2004; Smultea et al. 2004; Holst et al. 2005a,b, 2006). However, there is one recent summary report indicating that calling fin whales distributed in one 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 preliminary paper whether the whales ceased calling because of masking, or whether this was a behavioral response not directly involving masking.

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; Jochens et al. 2006, 2008). Madsen et al. (2006) noted that airgun sounds would not be expected to mask sperm whale calls given the intermittent nature of airgun pulses. 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; 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.

A few cetaceans are known to increase the source levels of their calls in the presence of elevated sound levels, or to shift their peak frequencies in response to strong sound signals (Dahlheim 1987; Au 1993; reviewed in Richardson et al. 1995:233*ff*, 364*ff*; Lesage et al. 1999; Terhune 1999; Nieukirk et al. 2005; Scheifele et al. 2005; Parks et al. 2007). These studies involved exposure to other types of anthropogenic sounds, generally of a more continuous nature than seismic pulses. It is not known whether these types of responses ever occur upon exposure to seismic sounds. If so, these adaptations, 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.

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). 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. 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). Weilgart (2007) also notes that even marine mammals that show no obvious avoidance or behavioral changes may still be adversely affected by noise. 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).

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 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 (NMFS 2005). Recently, a committee of specialists on noise impact issues has proposed new science-based impact criteria (Southall et al. 2007). 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.

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 kilometers, 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); Moulton and Miller (2005); Stone and Tasker (2006); Johnson et al. (2007); Nowacek et al. (2007) and Weir (2008a). 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 $\mu\text{Pa}_{\text{rms}}$ 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 $\mu\text{Pa}_{\text{rms}}$. 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 Whales.—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 $\mu\text{Pa}\cdot\text{m}_{\text{p-p}}$. 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 level of 157–164 dB re 1 $\mu\text{Pa}_{\text{rms}}$ (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 level for initial avoidance of an approaching airgun was 140 dB re 1 $\mu\text{Pa}_{\text{rms}}$ for humpback pods containing females, and at the mean CPA distance the received level was 143 dB re 1 $\mu\text{Pa}_{\text{rms}}$. One startle response was reported at 112 dB re 1 $\mu\text{Pa}_{\text{rms}}$. 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 level was 179 dB re 1 $\mu\text{Pa}_{\text{rms}}$. 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.

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 levels 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 levels up to 172 re 1 μPa on an approximate rms basis.

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).

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 Whales.—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, subtle but statistically significant changes in surfacing–respiration–dive cycles were evident upon statistical analysis. Bowheads usually did show strong avoidance responses when seismic vessels approached within a few kilometers (~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). 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 studies in the same region by Miller et al. (2005) and Harris et al. (2007) showed that many feeding bowhead whales tend to tolerate higher sound levels than migrating bowhead whales before showing an overt change in behavior. They found that, on the feeding grounds, bowhead whales are often seen from the operating seismic ship, though average sighting distances tend to be larger when the airguns are operating. However, some individual bowheads apparently begin to react at distances a few kilometers 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 kilometers.

Migrating bowhead whales in the Alaskan Beaufort Sea seem more responsive to noise pulses from a distant seismic vessel than are 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 from a medium-sized airgun source at received sound levels of around 120–130 dB re 1 μPa_{rms} (Miller et al. 1999; Richardson et al. 1999). 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 shooting stopped.

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

Gray Whales.—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 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 sound level of ~170 dB re 1 μPa$_{rms}$. Some slight behavioral changes were noted when approaching gray whales reached the distances where received sound 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 noise 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). It should be noted that the 2001 seismic program involved an unusually comprehensive combination of real-time monitoring and mitigation measures designed to avoid exposing western gray whales to received levels of sound above about 163 dB re 1 μPa$_{rms}$ (Johnson et al. 2007). 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.

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 reported in areas ensonified by airgun pulses (Stone 2003; MacLean and Haley 2004; Stone and Tasker 2006). 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 sightability, sighting rates for mysticetes (mainly fin and sei whales) were similar when large arrays of airguns were shooting 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 shooting compared with periods of no shooting ($P < 0.05$; Stone and Tasker 2006). In addition, fin/sei whales were less likely to remain submerged during periods of seismic shooting (Stone 2003).

In a study off Nova Scotia, Moulton and Miller (2005) found little difference in sighting rates (after accounting for water depth) and initial average sighting distances of balaenopterid whales when airguns were operating (mean = 1324 m) vs. silent (mean = 1303 m). However, there were indications that these whales were more likely to be moving away when seen during airgun operations. Baleen whales at the average sighting distance during airgun operations would have been exposed to sound levels (via direct path) of about 169 dB re 1 μPa_{rms} (Moulton and Miller 2005). Similarly, ship-based monitoring studies of blue, fin, sei and minke whales offshore of Newfoundland (Orphan Basin and Laurentian Sub-basin) found no more than small differences in sighting rates and swim directions during seismic vs. non-seismic periods (Moulton et al. 2005, 2006a,b). Analyses of CPA data yielded variable results.[7] The authors of the Newfoundland reports concluded that, based on observations from the seismic vessel, some mysticetes exhibited localized avoidance of seismic operations (Moulton et al. 2005, 2006a).

Minke whales have occasionally been observed to approach active airgun arrays where received sound levels were estimated to be near 170–180 dB re 1 µPa (McLean and Haley 2004).

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 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 scout boats operating in coordination with the seismic vessel (e.g., Smultea et al. 2004; Johnson et al. 2007).

Some baleen whales show considerable tolerance of seismic pulses. However, when the pulses are strong enough, avoidance or other behavioral changes become evident. Because 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.

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[7] The CPA of baleen whales sighted from the seismic vessels was, on average, significantly closer during non-seismic periods vs. seismic periods in 2004 in the Orphan Basin (means 1526 m vs. 2316 m, respectively; Moulton et al. 2005). In contrast, mean distances without vs. with seismic did not differ significantly in 2005 in either the Orphan Basin (means 973 m vs. 832 m, respectively; Moulton et al. 2006a) or in the Laurentian Sub-basin (means 1928 m vs. 1650 m, respectively; Moulton et al. 2006b). In both 2005 studies, mean distances were greater (though not significantly so) *without* seismic.

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, seismic 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 sound levels (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).

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 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 (Angliss and Outlaw 2008). 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 (Angliss and Outlaw 2008). Bowheads also have been observed over periods of days or weeks in areas ensonified repeatedly by seismic 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 effects.

5.2 Toothed Whales

Little systematic information is available about reactions of toothed whales to noise 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 (Jochens et al. 2006, 2008; Miller et al. 2006). 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).

Delphinids (Dolphins and similar) and Monodontids (Beluga).—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). 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).

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. Although the ramp-up procedure is a widely-used mitigation measure, it remains uncertain whether it is effective or not at alerting marine mammals and causing them to move away from seismic operations (Weir 2008b).

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 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).

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[8] airgun arrays were shooting. 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 shooting compared with periods of no shooting. 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 shooting (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 shooting (Stone and Tasker 2006). For most types of small odontocetes sighted by observers on seismic vessels, the median

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

CPA distance was ≥0.5 km larger during airgun operations (Stone and Tasker 2006). Killer whales appeared to be more tolerant of seismic shooting in deeper waters.

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 seismic than non-seismic periods (Smultea et al. 2004; Holst et al. 2005a, 2006). Monitoring results during a seismic survey in the Southeast Caribbean showed that the mean CPA of delphinids during seismic operations was 991 m compared with 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 during seismic operations there was 472 m compared with 178 m when the airguns were not operational (Holst et al. 2005a). The acoustic detection rates were nearly 5 times higher during non-seismic compared with seismic operations (Holst et al. 2005a).

For another two NSF-funded L-DEO seismic surveys that used a large 36 airgun array (~6600 in^3), the results cannot be easily interpreted, mostly due to small sample sizes. During a survey off Central America, the cetacean detection rate was greater and the mean CPA of delphinids was closer during seismic compared with non-seismic periods (Holst and Smultea 2008). For a survey in the Eastern Tropical Pacific, the cetacean detection rate was nearly 2.5 times greater during non-seismic compared with seismic periods, but the mean CPA was greater during periods when the airguns were not operating (Hauser et al. 2008).

During two seismic surveys off Newfoundland and Labrador in 2004–05, dolphin sighting rates were higher during non-seismic periods than during seismic periods after taking temporal factors into account, although the difference was statistically significant only in 2004 (Moulton et al. 2005, 2006a). In 2005, the mean CPA distance of dolphins was significantly closer during non-seismic periods (652 m vs. 807 m); in 2004, the corresponding difference was not significant.

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[9] airgun sources were operating, and effects on orientation were evident for all species and groups tested (Stone and Tasker 2006). Results from three NSF-funded L-DEO seismic surveys using small arrays (up to 3 GI guns and 315 in^3) were inconclusive. During a survey in the Eastern Tropical Pacific (Holst et al. 2005b) and in the Northwest Atlantic (Haley and Koski 2004), detection rates were slightly lower during seismic compared to non-seismic periods. However, mean CPAs were closer during seismic operations during one cruise (Holst et al. 2005b), and greater during the other cruise (Haley and Koski 2004). Interpretation of the data was confounded by the fact that survey effort and/or number of sightings during non-seismic periods during

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

both surveys was small. Results from another small-array survey in southeast Alaska were even more variable (MacLean and Koski 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 (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 noise pulses from underwater explosions (as opposed to airgun pulses) may be indicative of odontocete responses to very strong noise pulses. During the 1950s, small explosive charges were dropped into an Alaskan river in attempts to scare belugas 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 noise 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 noise 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 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 level 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 shooting vs. silent (Stone 2003; Stone and Tasker 2006). In contrast, 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). 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. Northern bottlenose whales sometimes are quite tolerant of slow-moving vessels not emitting airgun pulses (Reeves et al. 1993; Hooker et al. 2001). The few detections (acoustic or visual) of northern bottlenose whales from seismic vessels during recent seismic surveys off Nova Scotia have been during times when the airguns were shut down; no detections were reported when the airguns were operating (Moulton and Miller 2005; Potter et al. 2007). However, separate acoustic studies indicated that northern bottlenose whales continued to produce high-frequency clicks when exposed to sound pulses from distant seismic surveys (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; 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 noise 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; Jochens et al. 2006, 2008; Winsor and Mate 2006).

Recent and more extensive data from vessel-based monitoring programs in U.K. waters and off Newfoundland 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; Moulton et al. 2005, 2006a; Weir 2008a). 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. 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 levels 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).

Detailed studies of sperm whale reactions to seismic surveys have been done recently in the Gulf of Mexico (Gordon et al. 2006; Jochens et al. 2006, 2008; Madsen et al. 2006; Winsor and Mate 2006). In the Sperm Whale Seismic Study (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 sound exposures of airgun arrays in the Gulf of Mexico (Jochens et al. 2006, 2008). Whales were exposed to maximum received sound levels between 111 and 147 dB re 1 μPa_{rms} (131–164 dB re 1 $\mu Pa_{pk\text{-}pk}$) at ranges of ~1.4–12.6 km from the sound source. Although the tagged whales showed no horizontal avoidance, some whales changed foraging behavior during full-array exposure (Jochens et al. 2006, 2008).

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 have shown localized avoidance. Also, belugas 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 noise from sonars. Whether they ever do so in response to seismic survey noise 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 belugas 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. 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} (on the order of 2 or 3 km for a large airgun array).

5.3 Pinnipeds

Few studies of the reactions of pinnipeds to noise 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. 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 noise 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 noise 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 seismic 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 seismic 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 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 seismic pulses. 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 orient away whether or not the airguns were firing (Calambokidis and Osmek 1998). Bain and Williams (2006) also stated that their small sample of harbor seals and sea lions tended to orient 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 seismic pulses (Harris et al. 2001; Moulton and Lawson 2002). Those seismic projects usually involved arrays of 6–16 airguns with total volumes 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 airguns 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 meters, 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 meters 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 non-seismic periods. No consistent relationship was observed between exposure to airgun noise 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 seismic pulses, given the reduced airgun noise 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 during all seismic states, including periods without airgun operations. However, seals tended to be seen closer to the vessel during non-seismic than seismic periods. In contrast, during 2002, sighting rates of seals were higher during non-seismic periods than seismic operations, and seals were seen farther from the vessel during non-seismic compared to seismic activity (a marginally significant result). The combined data for both years showed that sighting rates were higher during non-seismic periods compared to seismic periods, and that sighting distances were similar during both seismic states. Miller et al. (2005) concluded that seals showed very limited avoidance to the operating airgun array.

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 pinnipeds frequently do not avoid the area within a few hundred meters of an operating airgun array. This minimal tendency for avoidance is a concern. It suggests that one cannot rely on pinnipeds to move away before received levels of sound from an approaching seismic survey vessel approach those that may cause hearing impairment (see below). However, previous telemetry work suggests that avoidance and other behavioral reactions may be stronger than evident to date from visual studies.

5.4 Sirenians, Sea Otter and Polar Bear

We are not aware of any information on the reactions of sirenians to airgun sounds

Behavior of sea otters along the California coast was monitored by Riedman (1983, 1984) while they were exposed to a single 100 in^3 airgun and a 4089 in^3 airgun array. No disturbance reactions were evident when the airgun array was as close as 0.9 km. Sea otters also did not respond noticeably to the single airgun. These results suggest that sea otters may be less responsive to marine seismic pulses than some other marine mammals, such as mysticetes and odontocetes (summarized above). Also, sea otters spend a great deal of time at the surface feeding and grooming (Riedman 1983, 1984). While at the surface, the potential noise exposure of sea otters would be much reduced by pressure-release and interference (Lloyd’s mirror) effects at the surface (Greene and Richardson 1988; Richardson et al. 1995).

Airgun effects on polar bears have not been studied. However, polar bears on the ice would be largely unaffected by underwater sound. Sound levels received by polar bears in the water would be attenuated because polar bears generally do not dive much below the surface and received levels of airgun sounds are reduced near the surface because of the aforementioned pressure release and interference effects at the water's surface.

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 quite precautionary, i.e., lower than necessary to avoid temporary auditory impairment let alone permanent auditory injury, at least for delphinids.
- TTS is not injury and does not constitute "Level A harassment" in U.S. MMPA terminology.
- 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 noise exposure criteria for marine mammals, frequency-weighting procedures, and related matters were published recently (Southall et al. 2007). Those recommendations have not, as of early 2009, been formally adopted by NMFS for use in regulatory processes and during mitigation programs associated with seismic surveys. However, some aspects of the recommendations have been taken into account in certain EISs and small-take authorizations. NMFS has indicated that it may issue new noise exposure criteria for marine mammals that account for the now-available 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, and other relevant factors. Preliminary information about possible changes in the regulatory and mitigation requirements, and about the possible structure of new criteria, was given by Wieting (2004) and NMFS (2005).

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 noise-induced hearing impairment and non-auditory physical effects.

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). Rather, the onset of TTS is an indicator that, if the animal is exposed to higher levels of that sound, physical damage is ultimately a possibility.

The magnitude of TTS depends on the level and duration of noise 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 noise ends. In terrestrial mammals, TTS can last from minutes or hours to (in cases of strong TTS) days. Only a few data have been obtained on sound levels and durations necessary to elicit mild TTS in marine mammals (none in mysticetes), and 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 and belugas. 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). 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.

Mooney et al. (2005) exposed a bottlenose dolphin to octave-band noise ranging from 4 to 8 kHz at SPLs of 160 to 172 dB re 1 µPa for periods of 1.8 to 30 min. Recovery time depended on the shift and frequency, but full recovery always occurred within 40 min. Consistent with the results of Finneran et al. (2005) based on shorter exposures, Mooney et al. reported that to induce TTS in a bottlenose dolphin, there is an inverse relationship of exposure time and SPL; as a first approximation, as exposure time was halved, an increase in noise SPL of 3 dB was required to induce the same amount of TTS. In other words, for toothed whales receiving single short exposures to non-impulse sound, the TTS threshold appears to be, to a first approximation, a function of the total energy received (Finneran et al. 2002, 2005).

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 μPa^2·s or 186 dB SEL (Finneran et al. 2002).[10] 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 kilometers 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 seismic pulses 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.

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.

The above TTS information for odontocetes is derived from studies on the bottlenose dolphin and beluga. There is no published TTS information for other types of cetaceans. However, preliminary evidence from a harbor porpoise exposed to airgun sound suggests that its TTS threshold may have been lower (Lucke et al. 2007).

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, it is necessary to determine the total energy that a mammal would receive as an airgun array approaches, passes at various CPA distances, and moves away. 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 and bottlenose dolphin.

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

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[10] If the low-frequency components of the watergun sound used in the experiments of Finneran et al. (2002) are downweighted as recommended by Miller et al. (2005a) and Southall et al. (2007) using their M$_{mf}$-weighting curve, the effective exposure level for onset of mild TTS was 183 dB re 1 μPa^2·s (Southall et al. 2007).

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). From this, it is suspected that received levels causing TTS onset may also be higher in mysticetes (Southall et al. 2007).

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 above, 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.[11]

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 energy fluxes of 161 and 163 dB re 1 $\mu Pa^2 \cdot s$ (Finneran et al. 2003). However, initial evidence from more prolonged (non-pulse) exposures suggested that some pinnipeds (harbor seals in particular) incur TTS at somewhat lower received levels than do small odontocetes exposed for similar durations (Kastak et al. 1999, 2005; Ketten et al. 2001). 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.

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.

***Sirenians, Sea Otter and Polar Bear*.—**There are no available data on TTS in sea otters and polar bears. However, TTS is considered unlikely to occur in sea otters or polar bears if they are on the water surface, given the pressure release and Lloyd's mirror effects at the water's surface. Furthermore, sea otters tend to inhabit shallow coastal habitats where large seismic survey vessels towing large spreads of

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[11] Three species of baleen whales that have been exposed to the onset of pulses from single airguns showed avoidance, specifically *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]. 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.

streamers may be unable to operate. TTS is also considered unlikely to occur in sirenians as a result of exposure to sounds from a seismic survey. They, like sea otters, tend to inhabit shallow coastal habitats and rarely range far from shore, whereas seismic survey vessels towing large arrays of airguns and (usually) even larger arrays of streamers normally must remain farther offshore because of equipment clearance and maneuverability limitations. Exposures of sea otters and sirenians to seismic surveys are more likely to involve smaller seismic sources that can be used in shallow and confined waters. The impacts of these are inherently less than would occur from a larger source of the types often used farther offshore.

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 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 in which the strongest pulse has a received level substantially exceeding 180 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—Lucke et al. 2007), 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 harbor seals) with a cumulative SEL of ~171 dB re 1 $\mu Pa^2 \cdot s$.

It has been shown that most large whales and many smaller odontocetes show at least localized avoidance of ships and associated seismic operations (see above). Even when avoidance is limited to the area within a few hundred meters of an airgun array, that should usually be sufficient to avoid the possibility of 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 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 whales 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 such that PTS is also 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).

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 (time required for sound pulse 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 likelihood 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 (Richardson et al. 1995, p. 372*ff*). Single or occasional occurrences of mild TTS are not indicative of permanent auditory damage.

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 at least 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). 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). 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.

More recently, 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 TTS threshold for an impulse). 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 (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 thesholds in those species. 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, respectively.

Sound impulse duration, peak amplitude, rise time, number of pulses, and inter-pulse interval are the main factors thought to determine the onset and extent of PTS. Ketten (1994) has noted that the criteria for differentiating the sound pressure levels that result in PTS (or TTS) are location and species-specific. 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, 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 shots would occur, and for the dependence of received SEL on distance in the region of the seismic operation.

It is unlikely that an odontocete would remain close enough to a large airgun 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 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) and perhaps also the harbor porpoise may be lower (Lucke et al. 2007; Southall et al. 2007). 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 marine mammals, caution is warranted given the limited knowledge about noise-induced hearing damage in marine mammals, particularly baleen whales, pinnipeds, and sea otters. 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.

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 either for seismic research or for commercial seismic surveys in marine areas; 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).

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 and acoustically-mediated bubble-growth 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.

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. • 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 (see below). 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).

6.4 Non-Auditory Physiological Effects

Based on evidence from terrestrial mammals and humans, sound is a potential source of stress (Wright et al. 2007a,b; Wright and Kuczaj 2007). However, almost no information is available on sound-induced stress in marine mammals, or on its potential to affect the long-term well-being or reproductive success of marine mammals (Fair and Becker 2000; Hildebrand 2005). In addition, information on the interactions of multiple environmental and anthropogenic stressors that could lead to potential cumulative impacts on marine mammal viability is also lacking (Wright et al. 2007a,b). Such long-term effects, if they occur at all, would be mainly associated with chronic noise exposure, which is not characteristic of most seismic surveys. As noted in Wright et al. (2007a), additional research is needed to best mitigate any potential stress and impacts of anthropogenic noise on marine mammals.

Romano et al. (2004) examined the effects of single underwater impulse sounds from a seismic water gun (up to 228 dB re 1 µPa · $m_{p\text{–}p}$) and single 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. During playbacks of drilling noise to four captive beluga whales, Thomas et al. (1990) found no changes in blood adrenaline or norarenaline, known as "stress hormones" ephinephrine and norepinephrine. Long-term effects were not measured, and no short-term effects were detected. Caution is necessary when extrapolating the small sample sizes, use of captive animals, and other technical limitations of these two studies to wild animals and situations. Further information about the occurrence of noise-induced stress in marine mammals is not available at this time.

Other types of physiological effects that have been mentioned as perhaps being 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 to occur upon exposure to airgun pulses. 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. 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 of this upon exposure to airgun pulses.

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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APPENDIX B:

REVIEW OF EFFECTS OF AIRGUN SOUNDS ON SEA TURTLES[12]

The following subsections review relevant information concerning the potential effects of airgun sounds on sea turtles. This information is included here as background for the briefer summary of this topic included in § IV of the EA. This background material is little changed from corresponding subsections included in IHA applications and EAs submitted to NMFS for previous L-DEO seismic surveys. Those documents concerned L-DEO projects in the following areas: northern Gulf of Mexico, Hess Deep (Eastern Tropical Pacific), Norwegian Sea, Mid-Atlantic Ocean, Southeast Caribbean, Southeast Alaska, Blanco Fracture Zone (northeast Pacific), Eastern Tropical Pacific off Central America, southern Gulf of Mexico (Yucatán Peninsula), and Aleutian Islands, Alaska. Much of this information has also been included in varying formats in other reviews, assessments, and regulatory applications prepared by LGL Ltd., environmental research associates.

(a) Sea Turtle Hearing

Although there have been a limited number of studies on sea turtle hearing, the available data are not very comprehensive. However, the available data show that sea turtles can hear moderately low-frequency sounds, including some of the frequencies that are prominent in airgun pulses.

Ridgway et al. (1969) and Lenhardt et al. (1985) provide detailed descriptions of the sea turtle ear structure; the reader is referred to those documents for further detail. Sea turtles do not have external ears. However, the sea turtle middle ear is well designed as a peripheral component of a bone conduction system. The thick tympanum, which is unique to sea turtles, is disadvantageous as an aerial receptor, but likely enhances low-frequency bone conduction hearing (Lenhardt et al. 1985). The tympanum acts as additional mass loading to the middle ear, which in mammals increases low-frequency bone conduction sensitivity (Tonndorf 1966 *in* Lenhardt et al. 1985). Sea turtles may be able to localize the direction from which an underwater sound is being received (Lenhardt et al. 1983). There is also the possibility that the middle ear functions as a "traditional aerial" receptor underwater. Any air behind the tympanum could vibrate, similar to the air in a fish swim bladder, and result in columellar motion (Lenhardt et al. 1985). (The columella of turtles takes the place of the three middle-ear ossicles in mammals.) Turtle hearing may involve both bone conduction and air conduction. However, it is likely that the path of sound energy to the sea turtle ear involves water/bone conduction and not air conduction, as sea turtles spend the majority of their time underwater (Musick and Limpus 1997).

Ridgway et al. (1969) obtained the first direct measurements of hearing sensitivity in any sea turtle. They used an electrophysiological technique (cochlear potentials) to determine the response of green sea turtle ears to aerial and vibrational stimuli that produced tones from 30 to 700 Hz. They found that green turtles exhibit maximum hearing sensitivity between 300 and 500 Hz, and speculated that the turtles had a useful hearing span of 60–1000 Hz. (However, there was some response to strong vibrational signals at frequencies down to the lowest one tested—30 Hz.) Electrophysiological measures of hearing in other types of animals have shown that those methods provide good information about relative sensitivity to

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[12] By **Valerie D. Moulton and W. John Richardson**, LGL Ltd., environmental research associates. November 2000.

different frequencies, but may underestimate the frequency range to which the animal is sensitive, and may not determine the absolute hearing thresholds very precisely.

Moein Bartol et al. (1999) tested the hearing of juvenile loggerhead turtles. The authors used a standard electrophysiological method (auditory brainstem response, ABR) to determine the response of the sea turtle ear to two types of vibrational stimuli: (1) brief, low-frequency broadband clicks, and (2) brief tone bursts at four frequencies from 250 to 1000 Hz. They demonstrated that loggerhead sea turtles hear well between 250 and 1000 Hz; within that frequency range, the turtles were most sensitive at 250 Hz. The authors did not measure hearing sensitivity below 250 Hz or above 1000 Hz. There was an extreme decrease in response to stimuli above 1000 Hz, and the vibrational intensities required to elicit a response may have damaged the turtle's ear. The signals used in this study were very brief—0.6 ms for the clicks, and 0.8–5.5 ms for the tone bursts. In other animals, auditory thresholds decrease with increasing signal duration up to about 100–200 ms. Thus, sea turtles probably could hear weaker signals than demonstrated in the study if the signal duration were longer.

Moein et al. (1994) used a related evoked potential method to test the hearing of loggerhead sea turtles exposed to a few hundred pulses from a single airgun. Turtle hearing was tested before, within 24 h after, and two weeks after exposure to pulses of airgun sound. Levels of airgun sound to which the turtles were exposed were not specifically reported. (The exposures to airgun sound are described in more detail in the next section, on behavioral reactions.) The authors concluded that five turtles (of ~11 tested?) exhibited some change in their hearing when tested within 24 h after exposure relative to pre-exposure hearing, and that hearing had reverted to normal when tested two weeks after exposure. The results are consistent with the occurrence of Temporary Threshold Shift (TTS), i.e. temporary hearing impairment, upon exposure of the turtles to airgun pulses. Unfortunately, the report did not state the size of the airgun used, or the received sound levels at various distances. The distances of the turtles from the airgun were also variable during the tests; the turtle was about 30 m from the airgun at the start of each trial, but it could then either approach the airgun or move away to a maximum of about 65 m during subsequent airgun pulses. Thus, the levels of airgun sounds that apparently elicited TTS are not known. Nonetheless, it is noteworthy that there was evidence of TTS from exposure to pulses from a single airgun. However, it may be relevant that the turtles were confined and unable to move more than about 65 m away. Turtles in the open sea might move away, resulting in less exposure than occurred during the experiment.

In summary, the limited available data indicate that the frequency range of best hearing sensitivity by sea turtles extends from roughly 250–300 Hz to 500–700 Hz. Sensitivity deteriorates as one moves away from this range to either lower or higher frequencies. However, there is some sensitivity to frequencies as low as 60 Hz, and probably as low as 30 Hz. Thus, there is substantial overlap in the frequencies that sea turtles detect *vs*. the frequencies in airgun pulses. Given that, plus the high levels of airgun pulses, sea turtles undoubtedly hear airgun sounds. We are not aware of measurements of the absolute hearing thresholds of any sea turtle to waterborne sounds similar to airgun pulses. Given the high source levels of airgun pulses and the substantial levels even at distances many km away from the source, sea turtles probably can hear distant seismic vessels. However, in the absence of relevant absolute threshold data, we cannot estimate how far away an airgun array might be audible. The apparent occurrence of TTS in loggerhead turtles exposed to pulses from a single airgun ≤65 m away suggests that sounds from an airgun array could cause at least temporary hearing impairment in sea turtles if they do not avoid the (unknown) radius where TTS occurs.

(b) Effects of Airgun Pulses on Behavior and Movements

Effects of exposure to airgun pulses on the behavior and distribution of various marine animals have been studied during the past two decades. Most of these studies have concerned marine mammals and fish, as reviewed by Richardson et al. (1995) and Gordon et al. (2004) for marine mammals, and Thomson et al. (2001) for fish. There have been far fewer studies of the effects of airgun noise (or indeed any type of noise) on sea turtles. We are aware of three such studies, each of which focused on short-term behavioral responses of sea turtles in enclosures to single airguns. Comparisons of results among studies are difficult because experimental designs and reporting procedures have varied greatly, and only one of the studies provided specific information about the levels of the airgun pulses received by the turtles. We are not aware of any studies on responses of free-ranging sea turtles to seismic sounds or on the long-term effects of seismic or other sounds on sea turtles.

The most recent of the studies of caged sea turtles exposed to airgun pulses was a study by McCauley et al. (2000) off Western Australia. This is apparently the only such study in which received sound levels were estimated carefully. McCauley et al. exposed caged green and loggerhead sea turtles (one of each) to pulses from an approaching and then receding 20-in^3 airgun operating at 1500 psi and 5 m airgun-depth. The single airgun fired every 10 s. There were two trials separated by two days; the first trial involved ~2 h of airgun exposure and the second ~1 h. The results from the two trials showed that, above a received level of 166 dB re 1 µPa (rms) [13], the turtles noticeably increased their speed of swimming relative to periods when no airguns were operating. The behavior of the sea turtles became more erratic when received levels exceeded 175 dB re 1 µPa rms. The authors suggested that the erratic behavior exhibited by the caged sea turtles would likely, in unrestrained turtles, be expressed as an avoidance response (McCauley et al. 2000).

O'Hara and Wilcox (1990) tested the reactions to airguns of loggerhead sea turtles held in a 300 x 45 m area of a canal 10 m deep in Florida. Nine turtles were tested at different times. The sound source consisted of one 10 in^3 airgun plus two 0.8 in^3 "poppers" operating at 2000 psi [14] and airgun-depth 2 m for prolonged periods: 20-36 hours in duration. The turtles maintained a standoff range of about 30 m when exposed to airgun pulses every 15 s or every 7.5 s. It was also possible that some turtles remained on the bottom of the enclosure when exposed to airgun pulses. O'Hara and Wilcox (1990) did not measure the received airgun sound levels. McCauley et al. (2000) estimated that "the level at which O'Hara saw avoidance was around 175–176 dB re 1 µPa rms". The levels received by the turtles in the Florida study probably were actually a few dB less than 175–176 dB because the calculations by McCauley et al. apparently did not allow for the shallow 2-m airgun depth in the Florida study. The effective source level of airguns is less when they are near 2 m depth than at 5 m (Greene et al. 2000).

Moein et al. (1994) investigated the avoidance behavior and physiological responses of loggerhead turtles exposed to an operating airgun, as well as the effects on their hearing as summarised earlier. The

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[13] rms = root mean square. This measure represents the average received sound pressure over the duration of the pulse, with duration being defined in a specific way (from the time when 5% of the pulse energy has been received to the time when 95% of the energy has been received). The rms received level of a seismic pulse is typically about 10 dB less than its peak level, and about 16 dB less than its peak-to-peak level (Greene et al. 1997, 2000; McCauley et al. 1998, 2000).

[14] There was no significant reaction by five turtles during an initial series of tests with the airguns operating at the unusually low pressure of 1000 psi. The source and received levels of airgun sounds would have been substantially lower when the air pressure was only 1000 psi than when it was at the more typical operating pressure of 2000 psi.

turtles were held in a netted enclosure about 18 m by 61 m by 3.6 m deep, with an airgun of unspecified size at each end. Only one airgun was operated at any one time; firing rate was one shot every 5-6 s. Ten turtles were tested individually, and seven of these were retested several days later. The airgun was initially discharged when the turtles were near the centre of the enclosure and the subsequent movements of the turtles were documented. The turtles exhibited avoidance during the first presentation of airgun sounds at a mean range of 24 m, but the avoidance response waned quickly. Additional trials conducted on the same turtles several days later did not show statistically significant avoidance reactions, although there was an indication of slight initial avoidance followed by rapid waning of the avoidance response. The authors described the rapid waning of the avoidance response as "habituation". Their auditory study indicated that exposure to the airgun pulses may have resulted in temporary hearing impairment (TTS, see earlier). Reduced hearing sensitivity may also have contributed to the waning response upon continued exposure. There was some evidence from the physiological measurements of increased stress in the sea turtles, but this stress could also have been a result of handling of the turtles.

Once again, inconsistencies in reporting procedures and experimental design prevent direct comparison of this study with either McCauley et al. (2000) or O'Hara and Wilcox (1990). Moein et al. stated, without further details, that "three different decibel levels (175, 177, 179) were utilised" during each test. These figures probably are received levels in dB re 1 μPa, and probably relate to the initial exposure distance (mean 24 m), but these details were not specified. Also, it was not specified whether these values were measured or estimated, or whether they are expressed in peak-peak, peak, rms, SEL, or some other units. Given the shallow water in the enclosure (3.6 m), any estimates based on simple assumptions about propagation would be suspect.

Despite the problems in comparing these three studies, there is a consistent trend showing that, at some received level, sea turtles show avoidance of an operating airgun. McCauley et al. (2000) found evidence of behavioral responses when the received level from a single small airgun was 166 dB re 1 μPa rms, and avoidance responses at 175 dB re 1 μPa rms. Based on these data, McCauley et al. estimated that, for a typical airgun array (2678 in^3, 12-elements) operating in 100-120 m water depth, sea turtles may exhibit behavioral changes at approximately 2 km and avoidance around 1 km. These estimates are subject to great variation, depending on the seismic source and local propagation conditions.

A further potential complication is that sea turtles on or near the bottom may receive sediment-borne "headwave" signals from the airguns (McCauley et al. 2000). As previously discussed, it is believed that sea turtles use bone conduction to hear. It is unknown how sea turtles might respond to the headwave component of an airgun impulse, or to bottom vibrations.

A pair of related studies involving stimuli other than airguns may also be relevant. ***(1)*** Two loggerhead turtles resting on the bottom of shallow tanks responded repeatedly to low frequency (20-80 Hz) tones by becoming active and swimming to the surface. They remained at the surface or only slightly submerged for the remainder of the 1-min trial (Lenhardt 1994). Although no detailed data on sound levels at the bottom vs. surface were reported, the surfacing response probably reduced the levels of underwater sound to which the turtles were exposed. ***(2)*** In a separate study, a loggerhead and an Atlantic ridley sea turtle responded similarly when 1-s vibratory stimuli at 250 or 500 Hz were applied to the head for 1 s (Lenhardt et al. 1983). There appeared to be rapid habituation to these vibratory stimuli. The tones and vibratory stimuli used in these two studies were quite different from airgun pulses. However, it is possible that resting sea turtles may exhibit a similar "alarm" response, possibly including surfacing, when exposed to any audible noise, regardless of whether it is a pulsed sound or tone.

(c) Possible Impacts of Airgun Sounds

The limited available data indicate that sea turtles will hear airgun sounds, and that exposure to a series of shots from a single airgun at close range may reduce sea turtle hearing sensitivity for a short period of time (temporary threshold shift or TTS). It is not known whether received sounds from a full-scale array could ever be strong enough to cause permanent hearing damage. Regarding behavioral and distributional effects, resting turtles are likely to become active, and avoidance reactions are likely to occur. Little is known about the sound levels that will or will not elicit various types of behavioral reactions. Although limited information is available about short-term effects of exposure to sounds from a single airgun, the long term effects (if any) of a marine seismic operation on sea turtles are unknown.

Hearing Loss

Noise-induced hearing damage can be either temporary or permanent. In general, the received sound must be strong for either to occur, and must be especially strong and/or prolonged for permanent impairment to occur.

There have been few studies that have directly investigated hearing or noise-induced hearing loss in sea turtles. In a study on the effect of sound pulses from a single airgun of unspecified size on loggerhead sea turtles, Moein et al. (1994) observed apparent TTS after exposure to a few hundred airgun pulses at distances no more than 65 m. The hearing capabilities had returned to “normal” when the turtles were re-tested two weeks later. Studies with terrestrial reptiles have also demonstrated that exposure to impulse noise can cause hearing loss. Desert tortoises (*Gopherus agassizii*) exhibit TTS after exposure to repeated high intensity sonic booms (Bowles et al. 1999). Recovery from these temporary hearing losses was usually rapid (<1 h), which suggested that tortoises can tolerate these exposures without permanent injury (Bowles et al. 1999). However, there are no data to indicate whether or not there are any plausible situations in which exposure to repeated airgun pulses at close range could cause permanent hearing impairment in sea turtles.

Behavioral avoidance and hearing damage are related. If sea turtles exhibit little or no behavioral avoidance, or if they acclimate to seismic noise to the extent that avoidance reactions cease, sea turtles might sustain hearing loss if they are close enough to seismic sources.

Turtles in the area of seismic operations prior to start-up may not have time to move out of the area even if standard ramp-up (=soft-start) procedures are in effect. It has been proposed that sea turtles require a longer ramp-up period because of their relatively slow swimming speeds (Eckert 2000). However, it is unclear at what distance from a seismic source sea turtles will sustain hearing impairment, and whether there would ever be a possibility of exposure to sufficiently high levels for a sufficiently long period to cause irreversible hearing damage.

In theory, a reduction in hearing sensitivity, either temporary or permanent, may be harmful for sea turtles. However, very little is known about the role of sound perception in the sea turtle’s normal activities. Hence, it is not possible to estimate how much of a problem it would be for a turtle to have either temporary or permanent hearing impairment. ***(1)*** It has been suggested (Eckert 2000) that sea turtles may use passive reception of acoustic signals to detect the hunting sonar of killer whales (*Orcinus orca*), a known predator of leatherback sea turtles (Caldwell and Caldwell 1969). Further investigation is needed before this hypothesis can be accepted. Some communication calls of killer whales include components at frequencies low enough to overlap the frequency range where sea turtles hear. However, the echolocation signals of killer whales are at considerably higher frequencies and may be inaudible to sea turtles (see review of odontocete sounds in Chapter 7 of Richardson et al. 1995). ***(2)*** Hearing impairment, either temporary or permanent, might inhibit a turtle’s ability to avoid injury from vessels. ***(3)*** Hearing may play a role in navigation. For example, it has been proposed that sea turtles may identify their breeding beaches by their acoustic signature (Lenhardt et al. 1983). However, recent evidence suggests that visual, wave, and magnetic cues are the main navigational cues used by sea turtles, at least in the case of hatchlings and juveniles (Lohmann et al. 1997, 2001; Lohmann and Lohmann 1998).

Behavioral and Distributional Effects

In captive enclosures, sea turtles generally respond to seismic noise by increasing swimming speed and swimming away from the noise source. Animals resting on the bottom often become active and move toward the surface where received sound levels normally will be reduced. Unfortunately, data for free-ranging sea turtles exposed to seismic pulses are unavailable, and potential long-term behavioral effects of seismic exposure have not been investigated. The paucity of data precludes predictions of sea turtle responses to seismic noise. The possible responses of free-ranging sea turtles to seismic pulses could include

- avoiding the entire seismic survey area to the extent that they move to less preferred habitat;
- avoiding only the immediate area around the active seismic vessel, i.e. local avoidance of the source vessel but remain in the general area; and
- exhibiting no appreciable avoidance, although short-term behavioral reactions are likely.

Complete avoidance of an area, if it occurred, could exclude sea turtles from their preferred foraging or breeding area and could displace them to areas where foraging or breeding conditions are sub-optimal. However, we are not aware of any information that would indicate that sea turtles show more than localized avoidance of airguns.

The potential alteration of a migration route might have negative impacts. However, it is not known whether the alteration would ever be on a sufficient geographic scale, or be sufficiently prolonged, to prevent turtles from reaching an important destination.

Avoidance of a preferred foraging area because of seismic noise may prevent sea turtles from obtaining preferred prey species and hence could impact their nutritional status. However, it is highly unlikely that sea turtles would completely avoid a large area along a migration route. Available evidence suggests that the zone of avoidance around seismic sources is not likely to exceed a few kilometres (McCauley et al. 2000). Avoidance reactions on that scale could prevent sea turtles from using an important coastal area or bay if there was a prolonged seismic operation in the area. Sea turtles might be excluded from the area for the duration of the seismic operation, or they might remain but exhibit abnormal behavioral patterns (e.g., lingering at the surface where received sound levels are lower). Whether those that were displaced would return quickly after the seismic operation ended is generally unknown.

It is unclear whether exclusion from a particular nesting beach by seismic operations, if it occurred, would prevent or decrease reproductive success. It is believed that females migrate to the region of their birth and select a nesting beach (Miller 1997). However, the degree of site fidelity varies between species and also intra-seasonally by individuals. If a sea turtle is excluded from a particular beach, it may select a more distant, undisturbed nesting site in the general area (Miller 1997). For instance, Bjorndal et al. (1983 *in* Miller [1997]) reported a maximal intra-seasonal distance between nesting sites of 290 km. Also, it is uncertain whether a turtle that failed to go ashore because of seismic survey activity would abandon the area for that full breeding cycle, or would simply delay going ashore until the seismic vessel had moved to a different area.

The results of experiments and monitoring studies on responses of marine mammals and fish to seismic surveys show that any kind of response is possible, depending on species, time of year, activity of the animal, and other unknown factors. The same species may show different kinds of responses at different times of year or even on different days (Richardson et al. 1995; Thomson et al. 2001). It is reasonable to expect similar variability in the case of sea turtles exposed to airgun sounds. For example, sea turtles of different ages have very different sizes, behavior, feeding habits, and preferred water depths. Nothing specific is known about the ways in which these factors may be related to airgun sound effects. However, it is reasonable to expect lesser effects in young turtles concentrated near the surface (where levels of airgun sounds are attenuated) as compared with older turtles that spend more time at depth where airgun sounds are generally stronger.

(d) Conclusions

Based on available data concerning sea turtles and other marine animals, it is likely that sea turtles will exhibit behavioral changes and/or avoidance within an area of unknown size in the vicinity of a seismic vessel. There is also the possibility of temporary hearing impairment or perhaps even permanent hearing damage to turtles close to the airguns. However, there are few data on temporary hearing loss and no data on permanent hearing loss in sea turtles exposed to airgun pulses. Seismic operations in or near areas where turtles concentrate are likely to have the greatest impact. There are no specific data that demonstrate the consequences to sea turtles if seismic operations do occur in important areas at important times of year. Until there are sufficient new data to allow a reassessment, it would be prudent to avoid seismic operations near important nesting beaches or in any areas of known concentrated feeding during the times of year when those areas are in use by many sea turtles.

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APPENDIX C:

REVIEW OF POTENTIAL IMPACTS OF AIRGUN SOUNDS ON FISH[15]

Relevant literature on the effects of seismic survey sound on fish is reviewed in this section as a condensation and summary of a larger review conducted for the American Petroleum Institute (Buchanan et al. 2004). Research on fish has been conducted on individuals of species from a number of different orders. Material is presented here for freshwater, anadromous, and marine species. Hastings and Popper (2005) provide a comprehensive critical review of the known effects of sound received by fish.

It is often difficult to interpret studies on the effects of noise on marine animals because authors often do not provide received sound levels or they do not provide the sound measurement type including the physical phenomenon being measured, the range from the sound source, the water depth, and the appropriate units and references. Underwater sound levels are typically reported as a number of decibels referenced to a common level, usually 1 micro-Pascal (µPa) at a distance of 1 m (e.g., 180 dB µPa•m). However, the dB number can differ because of what we have called the "measurement type" as "zero to peak," "peak to peak," or averaged ("rms"). Unless measurement types are provided, it is difficult to provide direct comparisons between studies. It is essential to be aware of all units, references, ranges, what is being measured and how. With transient sounds, the time over which a measurement's data are collected becomes important (Madsen 2005). Treatments in Richardson et al. (1995) are helpful.

(a) Acoustic Capabilities

Animal sensory systems function to provide their bearers pertinent information about the physical, biotic, and social environments in which they find themselves. This is no less true in water than in air. Extensive work has been done to understand the structures, mechanisms, and functions of animal sensory systems in aquatic environments (Atema et al. 1988; Kapoor and Hara 2001; Collin and Marshall 2003). All fish species have hearing and skin-based mechanosensory systems (inner ear and lateral line systems, respectively). These systems inform them about their surroundings (Fay and Popper 2000). Any anthropogenic sound that affects fish hearing or other sensory systems may have important negative consequences for fish survival and reproduction. Potential negative effects include masking of important environmental sounds or social signals, displacing fish from their habitat, or interfering with sensory orientation and navigation.

Although there have been few or no studies on the audiology of most fish species, there is a growing body of work on representative species of a number of diverse fish taxa. For the most part, as compared to mammals, fish hearing is restricted to rather low frequencies. For any vertebrate animal to hear a sound, there must be a mechanism by which the beds of hair cells (Howard et al. 1988; Hudspeth and Markin 1994) of the inner ear are disturbed in such a way as to bend them and thereby cause a neural discharge (Popper and Fay 1999).

At least two major pathways have been identified for sound transmittance between source and ear. The first and most primitive are the otoliths, calcium carbonate masses of the inner ear of fish, which are denser than the rest of the fish and the surrounding water. When the fish, which is on the whole similar in density to water, moves in a sound field the denser otoliths lag slightly behind because of their inertia and the differential movement of fish and otolith comes to bear on the beds of sensory hair cells that underly

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the calcareous otolith masses in the inner ear. This motion is interpreted by the central nervous system as sound.

The swim bladder is the second sound pathway in a fish and it involves a structure that is much lower in density than the fish as a whole because it is filled with gas. Any such gas pocket, being more compressible and expandable than either water or fish tissue, will both contract and expand differentially and substantially more than the rest of the fish in a sound field. The bladder expands and contracts in the sound field, which is an alternating series of high and low pressure zones. Such a pulsating structure can become a secondary source of mechanical disturbance and re-radiate the sound's signal within the animal. Such a secondary source may be more or less effective at stimulating the inner ears depending on the amplitude and frequency of the pulsation and the distance and mechanical coupling between the gas bladder and the inner ears (Popper and Fay 1993).

The herrings and allies (Clupeiformes), some cods and allies (Gadiformes in part), some squirrelfishes (Perciform family Holocentridae, in part), and a number of other fish have specialized swim bladders which extend more or less close to the inner ear. These fish have been found to have more sensitive hearing than fish lacking such specialization and are called '*hearing specialists*'. For these animals, the upper limit of the hearing frequency range can be from 1 to a few kHz.

Some species may only have a direct pathway to the inner ear (i.e., without swim bladders, with reduced swim bladders, or with swim bladders that are not connected or otherwise couples to the inner ear) and tend to have relatively poor auditory sensitivity. These species are known as '*hearing generalists*' (Popper and Fay 1999). It is important to recognize that the bladder itself is not a sensory end organ, but that the sound pathway involves sound energy re-radiation from the swim bladder to the ear. The ear in both hearing specialists and non-specialists is the ultimate sound detecting structure, and that detection involves relative motion between the otolith and the sensory hair cells.

A third mechanosensory pathway, the lateral line system found in most bony fishes and elasmobranchs (i.e., sharks), is sensitive to water motions. The basic sensory unit of the lateral line system is the neuromast, which is a bundle of sensory and supporting cells whose projecting cilia, similar to those in the ears, are encased in a gelatinous cap. For example, as a fish approaches an object, such as a rock or the glass wall of an aquarium, the pressure waves around its body are distorted, and these changes are quickly detected by the lateral line system, enabling the fish to swerve or to take other suitable action. Generally, fish use the neuromasts to detect low frequency acoustic signals (160–200 Hz) over a distance of one to two body lengths. Typically, the lateral line is used in conjunction with other sensory information, including hearing (Sand 1981; Coombs and Montgomery 1999). Reviews of fish-hearing mechanisms and capabilities can be found in Fay and Popper (2000) and Ladich and Popper (2004).

Hearing Generalists <1 kHz

Currently most fishes, including cartilaginous fishes (the sharks, skates, rays, and chimeras of the Class Chondrichthys), are classified as hearing generalists. This is more the case in marine systems than in fresh water, where many hearing specialists are found. The generalists either do not have large gas pockets in their bodies (the gas bladder having been reduced or lost through evolution), or those pockets do not have close proximity or mechanical connections to the ear structures; thus, they are not very involved in sound transduction and perception (see next section). Salmon are hearing generalists (Hawkins and Johnstone 1978), as are flatfishes (Chapman and Sand 1974), and well as many other fish species.

Hearing Specialists 1–4 kHz

Hearing specialists are found in a diverse assortment of fish groups, and rather than being limited to a kHz or less in hearing, can hear up to several kHz. Most bony fish have some sort of gas-filled structure in their bodies that is thought to function in buoyancy regulation. Although some bottom-dwelling bony fish have secondarily lost the trapped gas pocket, the swim bladder (sometimes called a gas bladder) is the norm across most bony fish taxa. Swim bladders do not occur in all fish species and fish species without gas bladders include flatfishes and sculpins and some other very actively swimming fish such as some tunas.

In hearing specialists, this gas-filled structure or an extension thereof, is located very near to or mechanically coupled to the sensory structures of the inner ear. In some fish, the swim bladder is either very close to the inner ear or it is in direct physical contact to the inner ear by a system of small bones called Weberian ossicles. In cods, the connection is much less direct. Other examples of connections between the swim bladder and the inner ear include elongated gas ducts or extensions of the swim bladder. The swim bladder located near the inner ear expands and contracts in response to fluctuating sound pressure. The swim bladder serves to convert the changes in pressure to motions that are transmitted to the otoliths in the inner ear and then interpreted as sound. This increases both the sensitivity and sound frequency range that is accessible to the fish (Blaxter 1981).

Extreme Hearing Specialists >5 kHz

All members of the anadromous herring subfamily Alosinae (the anadromous shads and near-shore menhadens) that have thus far been studied respond to sounds over 100 kHz (Mann et al. 1997, 1998, 2001). Those sound frequencies are far higher than the acoustic sources used in seismic surveys, although it may be that fish of alosine species could hear some components of the sounds produced by the vessel sonar systems.

Fish ears respond to changes in pressure and particle motions (van Bergeijk 1967; Schuijf 1981; Kalmijn 1988, 1989; Schellert and Popper 1992; Hawkins 1993; Fay 2005). In general, underwater sound levels considered likely to stimulate the skin-borne lateral line system of fish are relatively low in frequency, less than about 150 Hz (Coombs et al. 1988, 1989; Coombs and Montgomery 1999). In addition, sound amplitude generally attenuates (decreases) with increasing distance from the sound source (exceptions can occur in water that is shallow relative to the sound's wavelength, see Hastings and Popper [2005]). Thus, even very powerful and low-frequency sound sources are unlikely to have profound effects at anything but rather short ranges (Kalmijn 1988, 1989). On the other hand, sound propagation is more efficient at lower frequencies, assuming boundary conditions, especially water depth, are adequate for sound propagation (Rogers and Cox 1988). As a result, low-frequency sound may be propagated over a considerable distance. Because seismic surveys are characterized by low-frequency sounds, this aspect needs to be considered with respect to potential impacts on fish and their auditory functions, the acoustic environments they inhabit, and their associated ecology.

(b) Potential Effects on Fish

Effects on Freshwater Fish

Popper et al. (2005) tested three fish species, including broad whitefish, after stimulation with five blasts of a seismic airgun with a received mean peak sound level of ~205 dB re 1 μPa (a received mean SEL of ~175 dB re 1 $\mu Pa^2 \cdot s$). The broad whitefish showed no TTS to this signal; in contrast, adult northern pike (a hearing generalist) and lake chub (a hearing specialist) showed 10–15 dB of hearing loss with complete recovery within 24 hr after exposure.

Effects on Marine Fish

The often-cited examples of evidence for damage to fish ears attributable to exposure to seismic airgun energy were provided by McCauley et al. (2000a,b; 2003) with pink snapper (a porgie of the family Sparidae). The fish were caged and exposed to a seismic airgun energy pulse every 10 s for a total of 1 hr and 41 min. The moving source SPL was just below 223 dB re 1 $\mu Pa_{p\text{-}p}$ at the source and the approximate received SPLs ranged between 165 and 209 dB re 1 $\mu Pa_{p\text{-}p}$. The energy was highest over the 20–70 Hz frequency range. Over 600 seismic pulses were emitted during exposure. The sensory epithelium of the inner ear sustained extensive damage as indicated by ablated hair cells. Damage was more extensive in the ears of fish sacrificed 58 days after exposure than in fish examined 18 hr after exposure. There was no evidence of repair or replacement of damaged sensory cells up to 58 days after exposure to the sound. The authors provided the following caveats: (1) fish were caged and unable to swim away from the seismic source, (2) only one species of fish was examined, (3) the impact on the ultimate survival of the fish is unclear, and (4) precise airgun exposure specifics required to cause the observed damage were not obtained (i.e., a few high SPL signals or the cumulative effect of many low to moderate SPL signals).

Pearson et al. (1992) investigated the effects of seismic airgun energy on the behaviors of captive rockfish. The single airgun had a source SPL of 223 dB re 1 $\mu Pa{\cdot}m_{0\text{-}p}$ and measured received SPLs were 137–206 dB re 1 $\mu Pa_{0\text{-}p}$. The authors reported that rockfish reacted to the airgun sounds by exhibiting varying degrees of startle and alarm responses, depending on the species and the received sound level. Startle responses were observed when the received SPL was at least 200 dB re 1 $\mu Pa_{0\text{-}p}$; alarm responses occurred at a minimum received SPL of 177 dB re 1 $\mu Pa_{0\text{-}p}$. Other observed behavioral changes included the tightening of schools, downward distributional shift, and random movement and orientation. Some fish rose in the water column and commenced to mill (i.e. “eddy”) at increased speed while others moved to the bottom of the enclosure and remained motionless. Pre-exposure behavior was reestablished within 20–60 min. of the cessation of seismic firing. The authors concluded that reasonable received SPL thresholds for obvious rockfish behavioral response and more subtle rockfish behavioral response are 180 dB re 1 $\mu Pa_{0\text{-}p}$ and 161 dB re 1 $\mu Pa_{0\text{-}p}$, respectively.

Skalski et al. (1992) studied the potential effects of seismic airgun energy on the distribution and level of catch of “rockfish” (in this case scorpaenids) through an experimental hook-and-line fishery. The source SPL of the single airgun was 223 dB re 1 $\mu Pa{\cdot}m_{0\text{-}p}$ and the received SPLs at the base of the rockfish aggregation ranged from 186–191 re 1 $\mu Pa_{0\text{-}p}$. Characteristics of the fish aggregations were assessed using echosounders. During long-term seismic airgun firing from a stationary source, there was an overall increase in depth of fish aggregation indicating a downward shift in distribution. The authors also observed a significant decline in total catch of rockfish during seismic firing. It should be understood that this approach was quite different from an actual seismic survey as the duration of exposure was much longer (i.e., more repetitious) than likely to occur in an actual survey; thus, these results should be interpreted as a “worst case”.

Caged European sea bass were exposed to multiple sound pressure waves from a moving seismic airgun array with a source SPL of ~210 dB re 1 µPa (unspecified measure type) (Santulli et al. 1999). The pulses were emitted every 25 s over a 2-hr period. The minimum distance between fish and seismic source was 180 m. The authors did not indicate any observed pathological injury to the sea bass. Blood was collected from both exposed fish (6 hr after exposure) and control fish (6 hr before exposure). The sera were subsequently analyzed for cortisol, glucose, and lactate levels. Levels of cortisol, glucose, and lactate were significantly higher in the sera from exposed fish compared to that from the control fish. The levels of all three chemicals returned to pre-exposure state within 72 hr of exposure (Santulli et al. 1999).

Santulli et al. (1999) also installed underwater video cameras in the cage positioned closest to the seismic transect in order to monitor the fish responses to seismic shooting. There were indications of a slight startle response in some of the sea bass when the seismic array was as far as 2.5 km from the cage. The proportion of fish displaying "startle" responses increased as the seismic source approached the cage. At 180 m, the sea bass were densely packed at the middle of the enclosure in random orientation, appearing more active than they had been under pre-exposure conditions. Normal behavior resumed about 2 hr after occurrence of airgun firing nearest the fish (Santulli et al. 1999).

Chapman and Hawkins (1969) tested the reactions of whiting (hake) in the wild to an airgun emitting low-frequency, high-amplitude pulses (220 dB re 1 µPa·m$_{0\text{-}p}$). Received SPLs were estimated at 178 dB re 1 µPa$_{0\text{-}p}$. The research vessel was anchored and the school of whiting was monitored with an echosounder. The airgun fired intermittently. Before the airgun was fired, the fish were at depths of 25–55 m. In response to the sound pulses, the fish dove and formed a compact layer below a depth of 55 m. By the end of an hour of exposure to the sound pulses, the fish had habituated: they rose in the water despite the continued presence of the sound pulses. The airgun was switched off and, when it resumed firing, the fish began to descend again. The habituation seems to have been of short duration. Assuming spherical spreading from the single airgun, received levels would have been 192 dB re 1 µPa at 25 m and 185 dB re 1 µPa at 55 m.

Hassel et al. (2003, 2004) studied the potential effects of exposure to airgun pulses on the behavior of captive lesser sandeel. Depth of the enclosure used to hold the sandeel was ~55 m. The airgun array had an estimated source SPL of 256 dB re 1 µPa·m (unspecified measure type), but received SPLs were not measured. Exposures were conducted over a 3-day period. No mortality attributable to exposure to the airgun sounds was noted. Behavior of the fish was monitored using underwater video cameras, echosounders, and commercial fishery data from regions closest to the study area. The approach of the seismic vessel appeared to cause an increase in tail-beat frequency although the sandeels still appeared to swim calmly. During seismic shooting, many fish exhibited startle responses, followed by flight from the immediate area. The frequency of occurrence of startle response seemed to increase as the operating seismic array moved closer to the fish. The sandeels stopped exhibiting the startle response once the seismic firing ceased. The sandeel tended to remain higher in the water column during the seismic firing and none of them were observed burying themselves in the soft substrate. The commercial fishery catch data from areas nearby the experimentation site were inconclusive.

Kostyvchenko (1973), in uncontrolled experiments, exposed the eggs of numerous fish species (anchovy, red mullet, crucian carp, blue runner) to various seismic sources, including seismic airguns. Even as close as 0.5 m from the source, over 75% of the eggs survived exposure to the airgun shots. Survival rate increased to over 90% at a distance of 10 m from the airgun source. The received SPLs of the airguns were ~215–233 dB re 1 µPa$_{0\text{-}p}$. Handling of larvae and adult fish with eggs can be an important component of stress and mortality. Kostyvchenko (1973) does not address that but does report high rates of survival.

Various species of demersal fishes, blue whiting and some small pelagics, were exposed to a seismic array with a source SPL of about 250 dB re 1 µPa·m (unspecified measure type) (Dalen and Knutsen 1986). Received SPLs estimated using the assumption of spherical spreading ranged from 200 to 210 dB re 1 µPa (unspecified measure type). Exposure to the seismic survey sound pulses occurred once every 10 s for a 1-week period. The authors assessed the pre- and post-exposure fish distributions by acoustic mapping with echosounders and sonars. The acoustic mapping results indicated a significant decrease in abundance of demersal fish (36%) after seismic firing; however, comparative trawl catches did not support this. There were also non-significant reductions in the abundances of blue whiting and small pelagics indicated by post-exposure acoustic mapping.

Eggs, yolk sac larvae, post-yolk sac larvae, post-larvae, and fry of various commercially important fish species (cod, saithe, herring, turbot, and plaice) were exposed to received SPLs ranging from 220 to 242 dB re 1 µPa (unspecified measure type) (Booman et al. 1996). These received levels corresponded to exposure distances ranging from 0.75–6 m. The authors reported some cases of injury and mortality but most of these occurred after exposures at very close range (i.e., <15 m). Rigor of anatomy and pathology were questionable.

La Bella et al. (1996) studied the effects of exposure to seismic survey sound energy on fish distributional behavior using echosounder monitoring and changes in catch rate of hake by trawl, and clupeoids by gill netting. The seismic source was a 16-airgun array with a source SPL of 210 dB re 1 µPa·m (unspecified measure type). The shot interval was 25 s and exposure durations ranged from 4.6 to 12 hr. Horizontal distributions did not appear to change as a result of exposure to seismic firing; however, there was some indication of a downward shift in the vertical distribution. The experimental fishing catch rates did not differ significantly between pre- and post-seismic fishing periods.

McCauley et al. (2000 a,b) exposed various caged fish species to 600+ seismic airgun pressure waves. They conducted 10 trials that involved the exposure of live caged specimens of 10 assorted marine fish species to firing airguns and simultaneous monitoring of changes in fish behavior using underwater video. Fixed seismic sources were used in five of the trials 10–30 m from the cage, and mobile seismic sources were used in the remaining five trials (as close as 5–15 m from the cage, and as far as 350–450 m from the cage). The received SPLs ranged from 146–195 dB re 1 μPa_{rms}. Fish exhibited startle responses to short range start-up firing and longer-range full energy firing (i.e., received SPLs of 182–195 dB re 1 μPa_{rms}. Smaller fish showed a tendency to display startle response more often. “Responses” were observed above received SPLs of 156–161 dB re 1 μPa_{rms}. The occurrence of both startle response and alarm response decreased over time. Other behavioral observations included downward distributional shift that was restricted by the 10 m x 6 m x 3 m cages, increase in swimming speed, and the formation of denser aggregations. Fish behavior appeared to return to pre-exposure state 15–30 min. after cessation of seismic firing.

Wardle et al. (2001) made behavioral observations of marine fish (primarily juvenile saithe, adult pollock, juvenile cod, and adult mackerel) inhabiting an inshore reef off Scotland using video and telemetry before, during, and after exposure to firing of a stationary airgun. The approximate received SPLs ranged from 195–218 dB re 1 $\mu Pa_{0\text{-}p}$. Pollock tagged in Scotland and the U.S. did not move away from the reef in response to the seismic firing and their diurnal rhythm did not appear to be affected. However, there was an indication of a slight and relatively minor effect on the long-term day-to-night movements of the pollock. Video camera observations indicated that fish exhibited startle responses (“C-starts”) to all received levels. If the seismic source was visually obvious to the fish, they fled from it, but if the source was not visible to the fish, they often continued to move toward it. Therefore, there was indication of fish response to visual stimuli rather than only to acoustic stimuli.

The potential effect on fish abundance and distribution of exposure to seismic survey sound was investigated by Slotte et al. (2004). The 12 days of seismic survey operations spread over a period of 1 month involved an array with a source SPL of 222.6 dB re 1 $\mu Pa{\cdot}m_{p\text{-}p}$. The SPLs received by the fish were not measured. Acoustic surveys of the local distributions of various kinds of pelagic fish, including herring, blue whiting, and mesopelagic species, were conducted during the seismic surveys. There was no strong evidence of short-term scaring effects in terms of horizontal distribution. With respect to vertical distribution, blue whiting and mesopelagics were distributed deeper (20–50 m) during the seismic survey compared to pre-exposure). The average densities of fish aggregations were lower within the seismic survey area and fish abundances appeared to increase in accordance with increasing distance from the seismic survey area.

Saetre and Ona (1996) applied a “worst-case scenario” mathematical model to investigate the effects of seismic energy on fish eggs and larvae. They concluded that mortality rates caused by exposure to seismic are so low compared to the natural mortality that the impact of seismic surveying on recruitment to a fish stock must be regarded as insignificant.

Effects on Anadromous Fish

In uncontrolled experiments on a very small sample of different groups of young salmonids, including Arctic cisco, fish were caged and exposed to various types of sound. One sound type was either a single firing or a series of four firings 10–15 s apart of a 300-in^3 seismic airgun at 2000–2200 psi (Falk and Lawrence 1973). Swim bladder damage was reported but no mortality was observed when fish were exposed within 1–2 m of a source SPL of ~230 dB re 1 µPa (unspecified measure), although the method of determination is unclear and the small sample size makes drawing statistically valid conclusions impossible.

Thomsen (2002) exposed rainbow trout and Atlantic salmon held in aquaculture enclosures to the sounds from a small airgun array. Received SPLs were 142–186 dB re 1 µPa$_{p\text{-}p}$. The fish were exposed to 124 pulses over a 3-day period. In addition to monitoring fish behavior with underwater video cameras, the authors also analyzed cod and haddock catch data from a longline fishing vessel operating in the immediate area. Eight of the 124 shots seemed to evoke only subtle behavioral reactions by the salmonids but overall behavioral impacts were minimal. No fish mortality was observed during and immediately after exposure. The author reported no significant effects on cod and haddock catch rates and the behavioral effects were hard to differentiate from normal behavior.

Weinhold and Weaver (1972, cited in Turnpenny et al. 1994) exposed caged coho salmon smolts to impulses from 330- and 660-in^3 airguns, resulting in received levels estimated at ~214–216 dB (units not given). No lethal effects were observed.

It should be noted that, in a recent and comprehensive review, Hastings and Popper (2005) take issue with many of the authors cited herein for problems with experimental design and execution, measurements, and interpretation. Hastings and Popper (2005) deal primarily with the possible effects of pile-driving sounds on fish, but they provide an excellent and critical review of the impacts to fish from other underwater anthropogenic sounds.

Effects on Fisheries (Indirect)

The most comprehensive experiments on the effects of seismic shooting on abundance and catch of fish were conducted in the Barents Sea by Engås et al. (1993, 1996). They investigated the effects of seismic airgun sounds on distributions, abundances, and catch rates of cod and haddock using acoustic mapping and experimental fishing with trawls and longlines. The maximum measured source SPL was ~248 dB re 1 µPa·m$_{0\text{-}p}$ but no measurements of the received SPLs were made. Davis et al. (1998) estimated the received SPL at the bottom below the array as 205 dB re 1 µPa$_{0\text{-}p}$, and at 178 dB re 1 µPa$_{0\text{-}p}$ at 18 km from the array. Engås et al. (1993, 1996) concluded that there were indications of distributional change during and immediately following the seismic survey (45–64% decrease in acoustic density in their sonar data). The lowest densities were within 9.3 km of the shooting area. They indicated that trawl catches of both cod and haddock were less after the seismic operations as compared to before. Longline catches of haddock and cod declined and increased, respectively, after the seismic firing.

Løkkeborg (1991), Løkkeborg and Soldal (1993), and Dalen and Knutsen (1986) examined effects of seismic shooting on catch of demersal fish such as cod and haddock. Løkkeborg (1991) examined the effect of seismic airgun discharges on the catch rate of cod. The source SPL of the airgun array was 239 dB re 1 μPa·m (unspecified measure type) but received SPLs were not measured. Approximately 43 hr of seismic shooting occurred during an 11-day period. There was an interval of 5 s between pulses. Catch rates decreased from 55% to 80% within the seismic survey area; this apparent effect persisted for at least 24 hr within 9.3 km of the survey area.

Turnpenny et al. (1994) examined results of these studies and the results of other studies on rockfish. They roughly estimated received sound levels at catch locations and estimated that catchability is reduced when received sound levels exceed 160–180 dB re 1 $\mu\text{Pa}_{0\text{-p}}$. They also estimated that reaction thresholds of fish without swim bladders, such as flatfish, would be about 20 dB higher. Given the variability in transmission loss in different areas, the sound levels that were actually received by the fish observed in these studies are not known.

Turnpenny and Nedwell (1994) also reported on the effects of seismic shooting on inshore bass fisheries in shallow U.K. waters (5–30 m deep). They used tagged fish and catch records. There was no reduction in bass catch on days when shooting took place. Results of the tagging study showed no migration out of the area. The airgun array had a source level of 250 dB re 1 $\mu\text{Pa}\cdot\text{m}_{0\text{-p}}$. Received levels in the fishing areas were estimated to have been 163–191 dB re 1 $\mu\text{Pa}_{0\text{-p}}$. Turnpenny and Nedwell (1994) concluded that effects on fisheries would be smaller in shallow nearshore waters than in deep water because attenuation of sound is more rapid in shallow water than in deep water. See Hastings and Popper (2005) for criticism of many of these reports.

Skalski et al. (1992) used a 100-in^3 airgun with a source level of 223 dB re 1 $\mu\text{Pa}\cdot\text{m}_{0\text{-p}}$ to examine effects on CPUE of rockfish. The ship with the airgun traversed the trial fishing area and then stood off while the fishing vessel deployed a set line, did three echosounder transects, and then deployed two more set lines, each for 20 min. Each fishing experiment lasted 1 hr 25 min. Received levels at the base of the rockfish aggregations were 186–191 dB re 1 $\mu\text{Pa}_{0\text{-p}}$. The CPUE of rockfish declined by an average of 52.4% when the airguns were operating. Skalski et al. (1992) believed that the reduction in catch resulted from a change in behavior of the fish. The fish schools descended to near the bottom when the airgun was firing, and the fish changed their swimming and schooling behavior. The fish did not disperse, but the authors hypothesized that dispersal could have occurred at a different location with a different bottom type. Skalski et al. (1992) did not continue fishing after airgun firing ceased. They speculated that CPUE would return to normal quickly in their experimental area because fish behavior returned to normal within minutes after the sounds ceased. However, in an area where sound had caused the fish to disperse, they suggested that a lowered CPUE might persist.

European sea bass were exposed to sounds from seismic airgun arrays with a source SPL of 262 dB re 1 $\mu\text{Pa}\cdot\text{m}_{0\text{-p}}$ and a maximum SPL at some unspecified frequency of 202 dB re 1 μPa·m (Pickett et al. 1994). The seismic survey was conducted over a period of 4–5 months. The study was intended to investigate the effects of seismic shooting on inshore bass fisheries. Information was collected through a tag and release program, and from the logbooks of commercial fishermen. Most of the 152 recovered fish from the tagging program were caught within 10 km of the release site, and it was suggested that most of these bass did not leave the area for any long-term period. With respect to the commercial fishery, no significant changes in catch rate were observed (Pickett et al. 1994).

Only the study conducted by Chapman and Hawkins (1969) addressed habituation. They found that fish quickly habituated to seismic survey sounds over the short term. The other studies did not address long-term habituation. Only Chapman and Hawkins (1969) and Skalski et al. (1992) followed the behavior of individual schools of fish. With the exception of the California studies of rockfish (Skalski et al. 1992), investigators did not measure received noise levels. Thus, it is not possible to say, with any certainty, what sound levels could cause reduction in catchability of cod and haddock.

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APPENDIX D:

REVIEW OF POTENTIAL IMPACTS OF AIRGUN SOUNDS ON MARINE INVERTEBRATES[16]

This appendix is intended to provide a more detailed summary of the limited data and literature available on what is known about the potential effects of underwater sound on marine invertebrates. Specific conditions and results of the studies including sound exposure levels and sound thresholds of responses are discussed as available.

The large amounts of energy released by underwater seismic survey equipment results in energy pulses with very high peak pressures (Richardson et al. 1995). This was especially true when chemical explosives were used for underwater surveys. Virtually all underwater seismic surveying is now done with airguns with comparatively lower peak pressures. However, the shock waves that result from underwater gas discharges are still high enough to have the potential to injure or kill animals close to the source. Less overt than those effects are the disturbances to normal behaviors that animals in the vicinity of such discharges may experience.

The following sections provide an overview of sound production and detection in invertebrates, and available information on the effects of exposure to sound on marine invertebrates, with an emphasis on seismic survey sound. The information includes results of studies of varying degrees of scientific veracity as well as anecdotal information.

(a) Sound Production

Most available information on acoustic abilities as they relate to marine invertebrates pertains to crustaceans, specifically lobsters, crabs and shrimps. Fewer acoustic-related studies have been conducted on cephalopods. Many invertebrates are capable of producing sound; this includes barnacles, amphipods, shrimp, crabs, and lobsters (Au and Banks 1998; Tolstoganova 2002). Invertebrates typically produce sound by scraping or rubbing various parts of their bodies, although they also produce sound in other ways. Sounds made by marine invertebrates may be associated with territorial behavior, mating, courtship, and aggression. On the other hand, some of these sounds may be incidental and not have any biological relevance. Sounds produced by invertebrates can range from 87 Hz to 200 kHz, depending on the species.

Both male and female American lobsters produce a buzzing vibration with their carapace when grasped (Pye and Watson III 2004; Henninger and Watson III 2005). Larger lobsters vibrate more consistently than smaller lobsters, suggesting that sound production is involved with mating behavior. Sound production by other species of lobsters has also been studied. Among deep-sea lobsters, sound level was more variable at night than during the day, with the highest levels occurring at the lowest frequencies.

While feeding, king crab produce pulsed sounds that appear to stimulate movement by other crabs receiving the sounds, including approach behavior (Tolstoganova 2002). King crab also appeared to produce 'discomfort' sounds when environmental conditions were manipulated. These discomfort sounds differ from the feeding sounds in terms of frequency range and pulse duration.

Snapping shrimp (*Synalpheus parneomeris*) are among the major sources of biological sound in temperate and tropical shallow-water areas (Au and Banks 1998). By rapidly closing one of its frontal chela (claws), a snapping shrimp generates a forward jet of water and the cavitation of fast moving water

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[16] By **John Christian, Bob Bocking, and Carl Schilt**, LGL Ltd., environmental research associates.

produces a sound. Both the sound and the jet of water appear to function as weapons in the territorial behavior of alpheidae shrimp. Measured source SPLs for snapping ship were 183–189 dB re 1 μPa·m$_{p\text{-}p}$ and extended over a frequency range of 2–200 kHz.

(b) Sound Detection

There is considerable debate about the hearing capabilities of aquatic invertebrates. Whether they are able to hear or not depends on how underwater sound and underwater hearing are defined. In contrast to fish and aquatic mammals, no physical structures have been discovered in aquatic invertebrates that are stimulated by the pressure component of sound. However, vibrations (i.e., mechanical disturbances of the water) characterize sound waves as well. Rather than being pressure-sensitive, invertebrates appear to be most sensitive to the vibrational component of sound (Breithaupt 2002). Statocyst organs may provide one means of vibration detection for aquatic invertebrates.

More is known about the acoustic detection capabilities in decapod crustaceans than in any other marine invertebrate group. Crustaceans appear to be most sensitive to sounds of low frequencies, i.e., <1000 Hz (Budelmann 1992; Popper et al. 2001). A study by Lovell et al. (2005) suggests greater sensitivity of the prawn (*Palaemon serratus*) to low-frequency sound than previously thought. Studies involving American lobster suggest that these crustaceans are more sensitive to higher frequency sounds than previously realized (Pye and Watson III 2004).

It is possible that statocyst hair cells of cephalopods are directionally sensitive in a way that is similar to the responses of hair cells of the vertebrate vestibular and lateral line systems (Budelmann and Williamson 1994). Studies by Packard et al. (1990), Rawizza (1995) and Komak et al. (2005) have tested the sensitivities of various cephalopods to water-borne vibrations, some of which were generated by low-frequency sound.

In summary, only a few studies have been conducted on the sensitivity of certain species to sound. Available data suggest that they are capable of detecting vibrations but they do not appear to be capable of detecting pressure fluctuations.

(c) Potential Seismic Effects

There are three categories of potential effects of exposure to sound on marine invertebrates: pathological, physiological, and behavioral. Pathological effects include lethal and sub-lethal injury to the animals, physiological effects include temporary primary and secondary stress responses, and behavioral effects refer to changes in exhibited behaviors (i.e., disturbance). The three categories should not be considered as independent of one another and are interrelated in complex ways. For example, it is possible that certain physiological and behavioral changes could potentially lead to an ultimate pathological effect on individual animals (i.e., mortality).

Pathological Effects

In water, acute injury or death of organisms as a result of exposure to sound might depend on two features of the sound source: the received peak pressure and the time required for the pressure to rise and decay. Generally, the higher the received pressure and the less time it takes for the pressure to rise and decay, the greater the chance of acute pathological effects. Considering the peak pressure and rise/decay time characteristics of seismic airgun arrays used today, the associated pathological zone for invertebrates would be expected to be small (i.e., within a few meters of the seismic source). Few studies have assessed the potential for pathological effects on invertebrates from exposure to seismic sound, and some of these results are questionable as summarized below.

The pathological impacts of seismic survey sound on marine invertebrates were investigated on a limited scale in a pilot study on snow crabs (Christian et al. 2003, 2004). Because this study has not been peer reviewed, results must be interpreted cautiously. Under controlled field experimental conditions captive adult male snow crabs, egg-carrying female snow crabs, and fertilized snow crab eggs were exposed to variable SPLs (191–221 dB re 1 $\mu Pa_{0\text{-}p}$) and SELs (<130–187 dB re 1 $\mu Pa^2 \cdot s$). Neither acute nor chronic (12 weeks after exposure) mortality was observed for the adult crabs. There was a significant difference in development rate noted between the exposed and unexposed fertilized eggs/embryos. The egg mass exposed to seismic energy had a higher proportion of less-developed eggs than the unexposed mass. It should be noted that both egg masses came from a single female and any measure of natural variability was unattainable (Christian et al. 2003, 2004).

Another limited study of the effects of seismic survey sound on invertebrates had serious design problems that impacted the interpretation of some of the results (Chadwick 2004). In 2003, a collaborative study was conducted in the southern Gulf of St. Lawrence, Canada, to investigate the effects of exposure to sound from a commercial seismic survey on egg-bearing female snow crabs (DFO 2004). Caged animals were placed on the ocean bottom at a location within the survey area and at a location outside of the survey area. The maximum received SPL was ~195 dB re 1 $\mu Pa_{0\text{-}p}$. The crabs were exposed for 132 hr of the survey, equivalent to many thousands of seismic shots of varying received SPLs. The animals were retrieved and transferred to laboratories for analyses. Neither acute nor chronic lethal or sub-lethal injury to the female crabs or crab embryos was indicated. DFO (2004) reported that some exposed individuals had short-term soiling of gills, antennules, and statocysts; bruising of the hepatopancreas and ovary; and detached outer membranes of oocytes. However, these differences could not be conclusively linked to exposure to seismic survey sound.

In a field study, Pearson et al. (1994) exposed Stage II larvae of the Dungeness crab to single discharges from a seven-airgun array and compared their mortality and development rates with those of unexposed larvae. For immediate and long-term survival and time to molt, this study did not reveal any statistically significant differences between the exposed and unexposed larvae, even those exposed within 1 m of the seismic source.

In 2001 and 2003, there were two incidents of multiple strandings of the giant squid on the north coast of Spain, and there was speculation that they were caused by exposure to geophysical seismic survey sounds occurring at about the same time in the Bay of Biscay (Guerra et al. 2004). A total of nine giant squid, either stranded or moribund surface-floating, were collected at these times. However, Guerra et al. (2004) did not present any evidence that conclusively links the giant squid strandings and floaters to seismic activity in the area. Based on necropsies of seven (six females and one male) specimens, there was evidence of acute tissue damage. The authors speculated that one female with extensive tissue damage was affected by the impact of acoustic waves. However, little is known about the impact of marine acoustic technology on cephalopods and the authors did not describe the seismic sources, locations, and durations of the Bay of Biscay surveys. In addition, there were no controls, the presence of seismic activity was entirely circumstantial, and the examined animals had been dead long enough for commencement of tissue degradation.

McCauley et al. (2000a,b) exposed caged cephalopods to noise from a single 20-in^3 airgun with maximum SPLs of >200 dB re 1 $\mu Pa_{0\text{-}p}$. Statocysts were removed and preserved, but at the time of publication, results of the statocyst analyses were not available. However, behavioral reactions were observed (see below). No squid or cuttlefish mortalities were reported as a result of these exposures.

Physiological Effects

Biochemical responses by marine invertebrates to acoustic stress have also been studied, albeit in a very limited way in studies that were not peer reviewed. The study of the biochemical parameters influenced by acoustic stress could possibly provide some indication of the acute extent of the stress and perhaps any subsequent chronic detrimental effects. Stress could potentially affect animal populations by reducing reproductive capacity and adult abundance.

Stress indicators in the haemolymph of adult male snow crabs were monitored immediately after exposure of the animals to seismic survey sound (Christian et al. 2003, 2004) and at various intervals after exposure. No significant acute or chronic differences between exposed and unexposed animals in terms of the stress indicators (e.g., proteins, enzymes, cell type count) were indicated. Again, this pilot study was not peer reviewed.

Pilot studies on the effects of exposure to seismic survey sound on American lobsters have recently been conducted by DFO, St. John's, Newfoundland. The received SPL during these studies was ~197 dB re 1 $\mu Pa_{0\text{-}p}$. Each exposure session consisted of 200 shots over a 33-min period. Preliminary results suggest that haemolymph parameters such as serum protein, enzyme, and calcium ion levels were depressed for days to weeks in lobsters exposed to seismic survey sound compared to control animals. These results might suggest disturbance to the osmoregulatory system (J. Payne, Research Scientist, DFO, St. John's, Newfoundland, personal communication). However, the lack of peer review of this study limits its validity.

Behavioral Effects

The very limited study of the effects of exposure to sound on marine invertebrates has not indicated any serious pathological and physiological effects. However, some recent studies have focused on potential behavioral effects on marine invertebrates.

Anecdotal information from Newfoundland, Canada, indicated that catch rates of snow crabs showed a significant reduction immediately following a pass by a seismic survey vessel (G. Chidley, Newfoundland fisherman, personal communication). Christian et al. (2003) investigated the behavioral effects of exposure to seismic survey sound on snow crabs. Eight animals were equipped with ultrasonic tags, released, and monitored for multiple days prior to exposure and after exposure. Received SPL and SEL were ~191 dB re 1 $\mu Pa_{0\text{-}p}$ and <130 dB re 1 $\mu Pa^2 \cdot s$, respectively. The crabs were exposed to 200 discharges over a 33-min period. None of the tagged animals left the immediate area after exposure to the seismic survey sound. Five animals were captured in the snow crab commercial fishery the following year, one at the release location, one 35 km from the release location, and three at intermediate distances from the release location.

Another approach used by Christian et al. (2003) involved exposure of caged snow crabs to seismic survey sound while monitoring the crabs with a remote video camera. The caged animals were placed on the ocean bottom at a depth of 50 m. Received SPL and SEL were ~202 dB re 1 $\mu Pa_{0\text{-}p}$ and 150 dB re 1 $\mu Pa^2 \cdot s$, respectively. The crabs were exposed to 200 discharges over a 33-min period. The snow crabs did not exhibit any overt startle response during the exposure period.

Christian et al. (2003) also investigated the pre- and post-exposure catchability of snow crabs during a commercial fishery. Received SPLs and SELs were not measured directly and likely ranged widely considering the area fished. Maximum SPL and SEL were likely similar to those measured during the telemetry study. There were seven pre-exposure and six post-exposure trap sets. Unfortunately, there was considerable variability in set duration because of poor weather. Results indicated that the catch-per-unit-effort did not decrease after the crabs were exposed to seismic survey sound.

Caged female snow crabs exposed to sound associated with a recent commercial seismic survey conducted in the southern Gulf of St. Lawrence, Canada, exhibited a higher rate of 'righting' than those crabs not exposed to seismic survey sound (J. Payne, Research Scientist, DFO, St. John's, Newfoundland, personal communication). 'Righting' refers to a crab's ability to return itself to an upright position after being placed on its back. Christian et al. (2003) made the same observation in their study.

The preliminary results from the previously discussed studies on the effects of exposure to seismic survey sound on American lobsters suggest that feeding behavior of exposed lobsters was reduced for several days following exposure (J. Payne, Research Scientist, DFO, St. John's, Newfoundland, personal communication). However, the lack of peer review of this study limits its validity.

More anecdotal information from Newfoundland, Canada, indicates that a school of shrimp observed on a fishing vessel sounder shifted downwards and away from a nearby seismic sound source (H. Thorne, Newfoundland fisherman, personal communication). This observed effect was temporary. Andriguetto-Filho et al. (2005) attempted to evaluate the impact of seismic survey sound on artisanal shrimp fisheries off Brazil. Bottom trawl yields were measured before and after multiple-day shooting of an airgun array with a source SPL of 196 dB re 1 μPa·m. Water depth in the experimental area ranged between 2 and 15 m. Results of the study did not indicate any significant deleterious impact on shrimp catches.

Caged brown shrimp reared under different acoustical conditions exhibited differences in aggressive behavior and feeding rate (Lagardère 1982). Those exposed to a continuous sound source showed more aggression and less feeding behavior. It should be noted that behavior and response to stress in a cage may be vastly different from behavior of animals in the wild.

McCauley et al. (2000a,b) provided the first evidence of the behavioral response of southern calamari squid exposed to seismic survey sound. McCauley et al. reported on the exposure of caged cephalopods (50 squid and two cuttlefish) to noise from a single 20-in^3 airgun. The cephalopods were exposed to both stationary and mobile sound sources. The two-run total exposure times of the three trials ranged from 69 to 119 min. at a firing rate of once every 10–15 s. The maximum SPL was >200 dB re 1 $\mu Pa_{0\text{-}p}$. Some of the squid fired their ink sacs apparently in response to the first shot of one of the trials and then moved quickly away from the airgun. In addition to the above-described startle responses, some squid also moved towards the water surface as the airgun approached. McCauley et al. (2000a,b) reported that the startle and avoidance responses occurred at a received SPL of 174 dB re 1 μPa_{rms}. They also exposed squid to a ramped approach-depart airgun signal whereby the received SPL was gradually increased over time. No strong startle response was observed (i.e., ink discharge) but alarm responses were observed once the received SPL reached a level in the 156–161 dB re 1 μPa_{rms} range.

Komak et al. (2005) also reported the results of a study of cephalopod behavioral responses to local water movements. In this case, juvenile cuttlefish exhibited various behavioral responses to local sinusoidal water movements of different frequencies between 0.01 and 1000 Hz. These responses included body pattern changing, movement, burrowing, reorientation, and swimming.

Low-frequency sound (<200 Hz) has also been used as a means of preventing settling/fouling by aquatic invertebrates such as zebra mussels (Donskoy and Ludyanskiy 1995) and balanoid barnacles (Branscomb and Rittschof 1984). There are no organs in mussels or barnacles to suggest any likelihood of sound detection. It is most likely that effects of the low-frequency sound on these invertebrates are mechanical in nature.

Although not demonstrated in the literature, masking can be considered a potential effect of anthropogenic underwater sound on marine invertebrates. Some invertebrates are known to produce sounds (Au and Banks 1998; Tolstoganova 2002; Latha et al. 2005) and the detection capabilities of others are partially known (Packard et al. 1990; Budelmann 1996; Jeffs et al. 2003; Lovell et al. 2005). The functionality of these sounds is not understood and it is not known whether they have any biological relevance or not. Masking of produced sounds and received sounds (e.g., conspecifics and predators), at least the particle displacement component, could potentially have adverse effects on marine invertebrates.

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