Environmental Assessment of a Marine Seismic Survey by ION Geophysical in the Beaufort Sea, October–December 2010

Prepared for

ION Geophysical
2105 City West Boulevard
Building III, Suite 900
Houston, TX 77042

By

LGL
Alaska Research Associates, Inc.

1101 East 76th Ave., Suite B; Anchorage, AK 99518

February 2010

LGL Report P1128-1

Suggested citation format:

LGL Alaska Research Associates, Inc. (LGL). 2010. Environmental Assessment of a marine seismic survey by ION Geophysical in the Beaufort Sea, October–December 2010. Prepared by LGL Alaska Research Assoc. Inc., Anchorage, AK, for ION Geophysical, Houston, TX. 173 pages.

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ABSTRACT

ION Geophysical (ION) plans to conduct a 2D seismic survey in the Alaskan Beaufort Sea extending from the U.S. – Canadian border in the east to Point Barrow in the west. Two survey lines also extend west of Point Barrow into the Chukchi Sea. The proposed survey will acquire seismic data from ~1 October to 15 December 2010. The purpose of seismic survey is to collect seismic reflection data that reveal the sub-bottom profile for assessments of geologic origin and potential petroleum reserves. Ultra-deep 2D lines, such as those to be collected, are used to better evaluate the evolution of the petroleum system at the basin level, including identifying source rocks, migration pathways, and play types. As its energy source, the seismic survey will employ a 28-airgun array with a total operating volume of 4330 in^3. The seismic survey will take place in water depths ranging from ~20 – >3500 m, with >62 of the survey conducted in depths >200 m.

ION is requesting that the National Marine Fisheries Service (NMFS) issue an Incidental Harassment Authorization (IHA) to authorize the incidental, i.e., not intentional, harassment of small numbers of cetaceans and seals should this occur during the seismic survey. ION is requesting a Letter of Authorization (LoA) from the U.S. Fish & Wildlife Service (USFWS) to allow incidental harassment of walruses and polar bears. The information in this Environmental Assessment (EA) supports the IHA and LoA application process. Alternatives addressed in this EA consist of a corresponding program at a different time with issuance of an associated IHA and LoA; and the no action alternative, with no IHA or LoA and no seismic survey.

Several species of cetaceans and pinnipeds inhabit the Beaufort Sea. Few species that may be found in the study area are listed as endangered under the U.S. Endangered Species Act (ESA). The bowhead whale is the endangered species of marine mammal most likely to occur within the survey area. The survey has been scheduled specifically to avoid the spring and fall bowhead whale migrations and subsistence hunts for villages of Barrow, Nuiqsut and Kaktovik.

Potential impacts on the environment due to the seismic survey would be primarily a result of the operation of the airgun source, although an echo sounder and ice profiler will also be operated. The project will also involve an icebreaker to assist the source vessel. The increased underwater noise may result in avoidance behavior by some marine mammals. An integral part of the planned survey is a monitoring and mitigation program to minimize impacts of the proposed activities on marine species present and on fishing and subsistence activities, and to document the nature and extent of any effects. Injurious impacts to marine mammals have not been demonstrated to occur near airgun arrays, and the planned monitoring and mitigation measures would minimize the possibility of such effects should they occur.

Protection measures designed to mitigate the potential environmental impacts will include the following: a minimum of one dedicated marine mammal observer (MMO) maintaining a visual watch during all daytime airgun operations on both the source vessel and icebreaker; a single observer on watch commencing 30 min before airgun operations start; power downs or shut downs of the airgun array when mammals are detected within or about to enter designated safety radii; and conducting the survey during a period when few bowheads and other whale species are likely to be present. A forward looking thermal imaging (FLIR) camera system mounted on the icebreaker, bright search lights, and night-vision devices (NVDs) will also be available to assist with detecting the presence of marine mammals on ice and in water in close proximity to survey operations during periods of poor visibility or nighttime observations. ION has committed to apply these measures in order to minimize disturbance to marine mammals and to minimize the risk of injuries or of other environmental impacts.

With the planned monitoring and mitigation measures, unavoidable impacts to each of the species of marine mammal that might be encountered are expected to be limited to short-term localized changes in behavior and distribution near the survey activities. At most, such effects may be interpreted as falling within the Marine Mammal Protection Act (MMPA) definition of "Level B Harassment". No long-term or significant effects are expected on individual marine mammals, or the populations to which they belong, or their habitats.

LIST OF ACRONYMS

~	approximately
ACP	Arctic Coastal Plain
ADFG	Alaska Department of Fish and Game
AEWC	Alaska Eskimo Whaling Commission
BLM	Bureau of Land Management
CI	Confidence Interval
CITES	Convention on International Trade in Endangered Species
dB re 1 µPa	decibels in relation to a reference pressure of 1 micropascal
DNV	Det Norske Veritas
EA	Environmental Assessment
ESA	(U.S.) Endangered Species Act
f(0)	sighting probability density at zero perpendicular distance from survey track line
g(0)	probability of seeing a group located directly on the survey trackline
h	hour
IHA	Incidental Harassment Authorization (under MMPA)
ION	ION Geophysical
in	inch
IUCN	International Union for the Conservation of Nature and Natural Resources
IWC	International Whaling Commission
kHz	kilohertz
kt	nautical mile per hour (1 knot = 1.853 km/h)
kW	kilowatt
LoA	Letter of Authorization (under MMPA)
LT	Long ton = 1016 kg
L-DEO	Lamont-Doherty Earth Observatory of Columbia University
LME	Large Marine Ecosystem
m	meter
min	minute
MMO	Marine Mammal Observer
MMPA	(U.S.) Marine Mammal Protection Act
MMS	Minerals Management Service
ms	millisecond
NEPA	National Environmental Policy Act
NMFS	National Marine Fisheries Service
NMML	National Marine Mammal Laboratory
NOAA	National Oceanic and Atmospheric Administration
NPFMC	North Pacific Fisheries Management Council
NSB	North Slope Borough
NSB-DWM	North Slope Borough Department of Wildlife Management
OCS	Outer Continental Shelf
pk	peak
psi	pounds per square inch
PTS	Permanent Threshold Shift
rms	root-mean-square

s	second
SE	Southeast
SEL	sound energy level
SPL	sound pressure level
TTS	Temporary Threshold Shift
U.K.	United Kingdom
UNEP	United Nations Environment Program
U.S.	United States of America
USDI	United States Department of the Interior
USFWS	U.S. Fish and Wildlife Service
USN	U.S. Navy
USGS	United States Geological Survey
WCMC	World Conservation Monitoring Centre

I. PURPOSE AND NEED

ION Geophysical (ION) plans to conduct a 2D seismic survey in portions of the Alaskan Beaufort Sea and northern Chukchi Sea in 2010. The survey will be conducted from the SR/V *Geo Explorer*, a seismic source vessel, with assistance from the M/V *Vladimir Ignatyuk*, an arctic class icebreaker. The purpose of the proposed survey is to collect seismic reflection data that reveal the sub-bottom profile for assessments of geologic origin and potential petroleum reserves. Ultra-deep 2D lines, such as those to be surveyed, are used to better evaluate the evolution of the petroleum system at the basin level, including identifying source rocks, migration pathways, and play types.

The purpose of this Environmental Assessment (EA) is to provide information needed to assess potential environmental impacts associated with an airgun array and other acoustic sources to be operated during the proposed cruise. The EA was prepared under the National Environmental Policy Act (NEPA). The EA addresses potential impacts of the proposed seismic survey from the *Geo Explorer* on marine mammals including cetaceans and pinnipeds which are under the jurisdiction of the National Marine Fisheries Service (NMFS). Much of the information presented in the EA for cetacean and pinniped species was also included in ION's permit application to NMFS. In addition the EA discusses other species not under NMFS jurisdiction including polar bear (*Ursus maritimus*), Pacific walrus (*Odobenus rosmarus*) and threatened eiders which are under the jurisdiction of the U.S. Fish and Wildlife Service (USFWS). The EA also discusses fisheries and subsistence harvesting in the Beaufort Sea.

Several species of cetaceans and pinnipeds inhabit the parts of the Beaufort Sea where this cruise will occur. A few species listed as endangered under the U.S. Endangered Species Act (ESA) may occur in certain portions of the survey area, most notably the bowhead whale and (although very unlikely) the fin whale. The polar bear was recently listed as a threatened species under the ESA (USFWS 2008). Other species of concern (birds) that might occur in the proposed project area are the spectacled (*Somateria fischeri*) and Steller's (*Polysticta stelleri)* eiders that are also listed as threatened.

Incidental Harassment Authorizations (IHAs) issued by the NMFS are often required prior to the start of offshore activities. IHAs authorize the "taking" (as defined under the Marine Mammal Protection Act) of small numbers of marine mammals incidental to the planned activities. 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, and must have negligible impacts on the species and stocks. The proposed project must "take by harassment" no more than small numbers of those species or stocks, and (where relevant) must not have an unmitigable adverse impact on the availability of the species or stocks for authorized subsistence uses. It is expected that all "takes" associated with the proposed activities will be Level B takes involving temporary behavioral changes and that no Level A "takes" involving injury to marine mammals will occur.

IHAs or Letters of Authorization (LOAs) are also issued by the USFWS for species under its jurisdiction including Pacific walrus and polar bear. IHAs and LOAs issued by the USFWS typically have compliance requirements similar to those of NMFS.

Mitigation measures to address potential environmental impacts are also described in this EA as an integral part of the planned activities. With the mitigation measures in place, any impacts on marine mammals and other species of concern 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 marine mammals or populations, on the subsistence harvest of marine mammals, on marine mammal habitat, or on the individuals and populations of other species.

II. ALTERNATIVES INCLUDING PROPOSED ACTION

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

Proposed Action

The project objectives and context, activities, and mitigation measures for the proposed activities planned by ION are described in the following subsections.

(1) Project Objectives and Context

ION plans to conduct a seismic survey in the Alaskan Beaufort Sea and northern Chukchi Sea. The seismic operations will be used to better evaluate the evolution of the petroleum system at the basin level, including identifying source rocks, migration pathways, and play types, as described above under “Purpose and Need”.

(2) Proposed Activities

(a) Location of the Activities

ION proposes to conduct a 2D seismic survey primarily in the Alaskan Beaufort Sea with two lines extending into the Chukchi Sea (Fig. 1). The survey area will be bounded approximately by 138º to 168º W longitude and 70º to 73º N latitude ranging from ~12 to 250 km offshore in water depths from <20 m to >3500 m. The survey area will cover the continental shelf, the continental slope, and the abyssal plain. The approximate length of the proposed survey lines is 7,250 km. For mitigation and operational reasons the survey area has been bisected by a line that runs from 70.5° N, 150.5° W to 73° N, 148° W (Fig. 1). Ice conditions permitting, ION plans to begin survey operations east of the line described above (eastern survey area; Fig. 1) in offshore waters (>1000 m) where bowheads are expected to be least abundant in early October. The survey will then progress to shallower waters in the eastern survey area before moving to the west survey area (Fig. 1) in late October or early November. Ice conditions during the survey are expected to range from open water to 10/10 ice cover. The airguns and hydrophone streamer towed by the *Geo Explorer* have been specially designed for operations in ice covered seas.

(b) Description of the Activities

Geophysical (seismic reflection and refraction) surveys will be conducted from the *Geo Explorer*, a 2D seismic source vessel. The *Geo Explorer* will deploy an airgun array comprised of 28 Bolt airguns with a total volume of 4330 in^3 and a single hydrophone streamer which will extend ~8.5 km behind the vessel. The *Geo Explorer* will follow the lead of the accompanying icebreaker, the *Vladimir Ignatyuk*, an arctic-class icebreaker, which will generally operate ~0.5-1 km ahead of the *Geo Explorer*.

The majority of the survey (62%) will be conducted in water depths >200 m, however, 19% of operations will occur in water depths ≤50 m. The survey will consist of 38 transect lines ranging in length from ~11 to 923 km and totaling ~7,250 km of trackline. After completion of the survey both vessels will exit from the western end of the study area and transit south through the Chukchi and Bering seas.

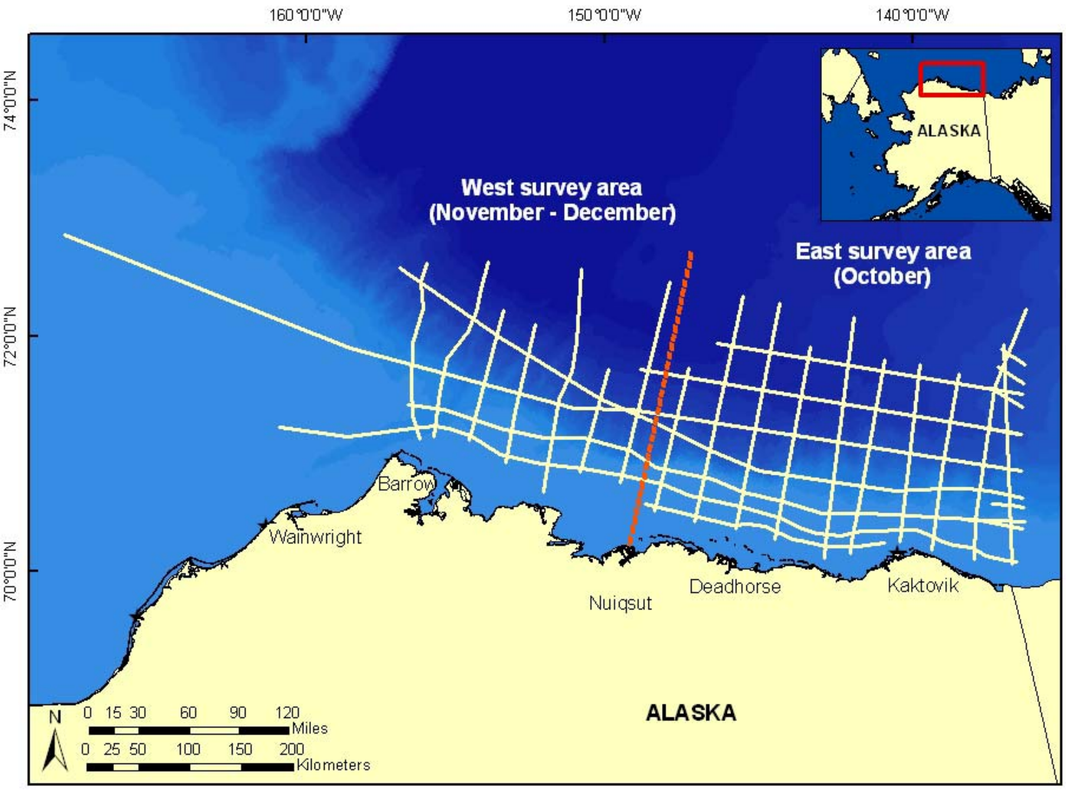

FIGURE 1. Proposed seismic survey lines for ION 2D seismic survey, Oct-Dec 2010. The red dashed line indicates the division between the "east survey area" and the "west survey area".

(c) Schedule

Both vessels will enter the Alaskan Beaufort Sea from Canadian waters on ~1 October and return to Dutch Harbor on or before~30 December. The seismic survey is scheduled to occur over ~76 days from ~1 October to 15 December 2010, though some variation is possible given the uncertainties in ice conditions and other environmental variables.

(d) Vessel Specifications

SR/V Geo Explorer

The seismic source vessel to be used is SR/V *Geo Explorer* (call sign LAFT7), an ice strengthened Det Norske Veritas (DNV) ice class 1A vessel (Fig. 2). The vessel was built in 1988 and has recently been modified for surveying in areas with ice. The *Geo Explorer* is owned by GC Rieber Shipping AS, operated by Hexio Geophysical AS, and is registered in Bergen, Norway. It is 65 m long, with a beam of 14 m and a draft (loaded) of 7.8 m. The *Geo Explorer* has a fresh water capacity of 47,000 L and is equipped with a fresh water generator. The *Geo Explorer* has a cruising speed of 13 kts, but will travel at a speed ranging from ~4 to 5 kts while conducting seismic operations. The vessel is equipped with standard navigation, radar, communication and depth sounding equipment. Details of the ships characteristics are presented below.

Figure 2. The seismic source vessel, SR/V *Geo Explorer,* planned for use by ION in the Alaskan Beaufort Sea in 2010 (photo by *V. Ignatyuk*, ice pilot).

Geo Explorer Ship Characteristics

Length, Overall	65 meters
Breadth	14 meters
Draft, Full Load	7.8 meters
Tonnage	2,782 GRT
Propulsion	Single Screw, variable pitch, running in nozzle
Main Engine	Wickmann 3000kW
Bow Thruster	1x Brunvoll electric; 365 kW
Electrical Power	2 x Cat 3512 -960 kW & 1 x Shaft gen -1814 kW
Emergency Generator	Cat 3412 – 495 kW
Fuel Capacity	650 m^3
Fresh water Capacity	47 m^3
Cruising Speed	13 knots
Operations Speed	4-5 knots
Accommodation	38 pers

Vladimir Ignatyuk

The M/V *Vladimir Ignatyuk* (Fig. 3), call sign UGTP, is an Arctic Class 4 ice-breaking ship that will be used to assist the *Geo Explorer*. Under ideal conditions, an Arctic Class 4 ship can navigate in winter conditions through solid unbroken ice approximately 1.2 m thick at speeds ≥3 kts, and aggressively break large ridges by backing and ramming.

Figure 3. The icebreaker, M/V *Vladimir Ignatyuk,* planned for use by ION in the Alaskan Beaufort Sea in 2010 (photo by T. Lang, LGL).

The *Vladimir Ignatyuk* is owned and operated by Murmansk Shipping Company under the Russian flag. It is a multifunctional icebreaker built in 1983. The *Vladimir Ignatyuk* is 88 m long, with a beam of 17.8 m and a draft of 8.3 m. It can travel at a speed of 15.5 kts, but cruising speed is 12.5 kts. It has a fuel oil capacity of 1,760,000 L, and a gross tonnage of 4,322 LT and net tonnage of 1,296 LT. It is powered by four Stork Werkspoor diesel engines, 5,600 hp each, and has two auxiliary diesels. It has two C.P.P. propellers and a bow thruster.

The *Vladimir Ignatyuk* will be used as an icebreaker to assist the seismic vessel to reach the Alaskan Beaufort Sea in September/October and for icebreaking during the proposed geophysical survey. While in the survey area, the *Vladimir Ignatyuk* will be used to break ice ahead of the *Geo Explorer* when surveying in areas of ice. The *Vladimir Ignatyuk* will normally operate ~0.5-1 km ahead of the *Geo Explorer*, but ice conditions at the time will determine the optimal escort distance from the seismic vessel.

Vladimir Ignatyuk Ship Characteristics

Length, Overall	88 meters
Breadth	17.8 meters
Draft	8.3 meters
Gross Tonnage	4,322 LT
Net Tonnage	1,296 LT
Propulsion Power	23,200 HP
Propellers	2 C.P.P 4 blades
Main Engine	four Stork Werkspoor diesel engines, 5,600 hp each
Auxiliary Diesels	2 x 750 KWT each
Thrusters Bow/Aft	Abt 1100 KWT/CPP 500 HP
Bollard Pull	Over 200 tonnes
Fuel Capacity	1760 m^3
Fresh water Capacity	41 m^3
Speed	15.5 knots
Icebreaking Capability	1.2 m @ 3 knots; continuous
Berth Total	34

(e) Airgun Description

The seismic source for the proposed geophysical survey will be comprised of 28 Bolt airguns with a total operating volume of 4330 in^3 (one airgun will serve as a spare). The 28 airguns will be distributed in two sub-arrays comprised of 14 airguns each (Fig. 4). Individual airgun sizes range from 65 to 350 in^3. Airguns will be operated at 2000 psi. The sub-arrays will be towed 25 m behind the source vessel, though this may need to be adjusted (e.g., up to 50 m) if conditions warrant, and at a water depth of ~8.5 m. The seismic vessel will travel along pre-determined lines at speeds ranging from ~4 to 5 knots. The airgun array will discharge every 50 m or about every 20 seconds.

The nominal zero-to-peak source pressure level @ 1 m for each pulse is estimated as 250 dB re 1µPa (for 1-2000 Hz). The source pressure averaged over the length of the pulse (rms) is estimated to be

232 dB re 1µPa @ 1 m and the sound exposure level (SEL) at 1 m from the source is estimated as 229 dB re 1 µPa^2 s. The pulse length (90% energy) is estimated to be 0.5 s near the source (Zykov et al. 2010).

The seismic source vessel will also tow a streamer which will receive the reflected signals from the bottom and transfer the data to an on-board processing system. ION is proposing to use a streamer called the DigiSTREAMER. The streamer will be ~ 8.5 km long, and will be towed ~9.5 m below the water surface. Approximately every 300 m along the streamer, DigiFIN units are attached to maintain the desired deployment depth. The DigiFIN units also provide lateral control for avoiding deep ice keels, acoustic positioning, and depth measurements. The survey vessel will have limited maneuverability while towing the streamer and thus will require a 10 km run-in for the start of a seismic line, and a 4-5 km run-out at the end of the line.

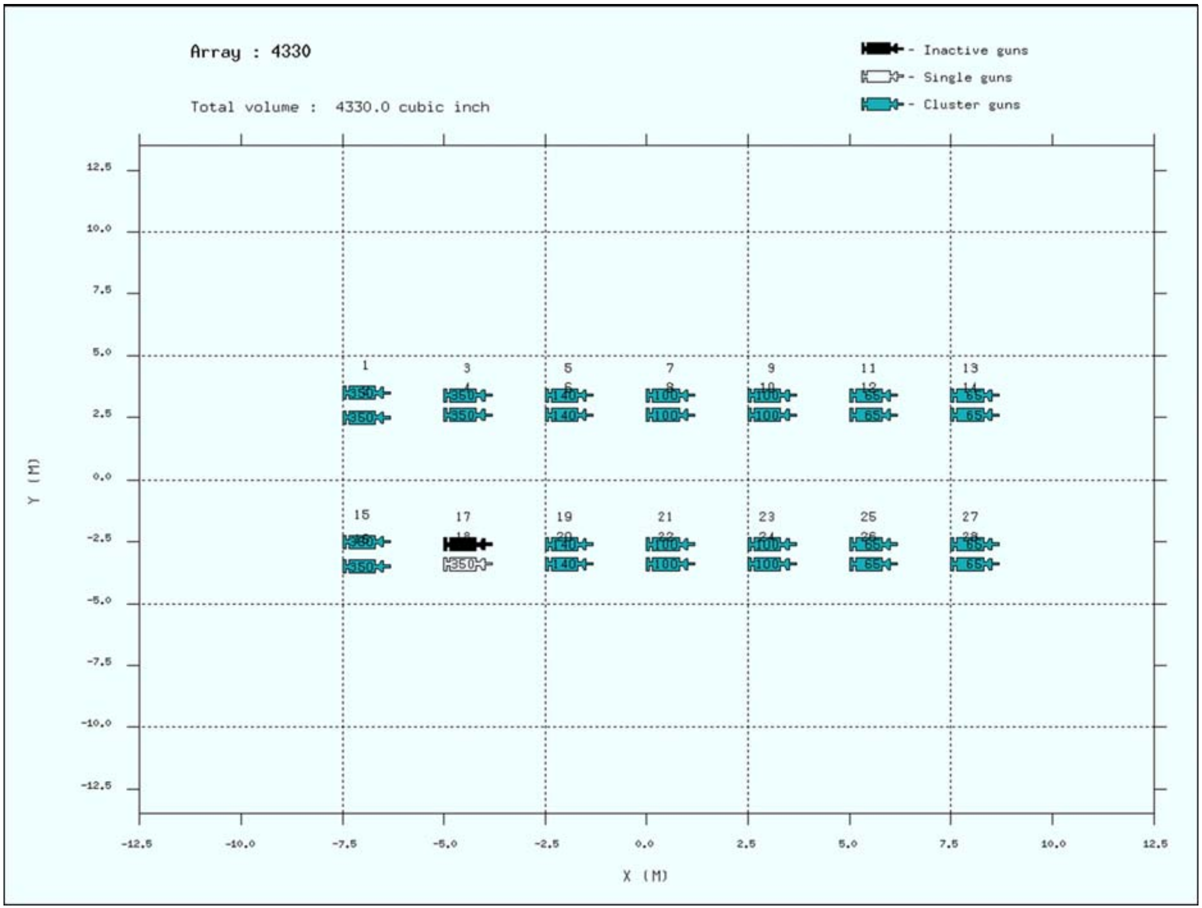

Figure 4. Geometry layout of 4330 in^3 array. Tow direction is to the right; tow depth is 8.5 m.

(f) Echo sounder and Ice Profiler

Along with the airgun operations, additional acoustic systems to be operated during the cruise will include a single-beam echo sounder and an ice profiler. These sources will operate throughout most of the cruise, and will generally operate simultaneously with the airgun array.

Echo sounder (Simrad EA 600)

The *Geo Explorer* will use a Simrad EA 600 echo sounder. The downward-facing single-beam Simrad EA 600 operates at frequencies ranging from 12 to 710 kHz with a maximum output power of 2 kW. It is expected that the echo sounder will be operated at 38 kHz with a pulse duration of 4 ms. The maximum ping rate is 20 pings per second. It can be used for water depths up to 10,000 m and provides up to 1 cm resolution.

Ice Profiler (ASL Ice Profiler IPS5)

The ice profiler will be operated from aboard the *Geo Explorer* to provide information on ice conditions in front of the vessel. The ice profiler has a narrow acoustic beam (1.8°) with a nominal source output of 228 dB re 1µPa @ 1m (unspecified measure type). The energy from the ice profiler is directed forward by a 420 kHz transducer mounted on the hull. The ice profiler produces sound pulses of programmable duration (68 ms long is standard) every 1 to 2 s.

(3) Mitigation Measures

Several species of marine mammals are known to occur in the proposed survey area. To minimize the likelihood that impacts will occur to marine mammal species and stocks, airgun operations will be conducted in accordance with all applicable U.S. federal regulations and IHA requirements. ION will coordinate all activities with the relevant U.S. Federal agencies, particularly the National Marine Fisheries Service (NMFS) and the U.S. Fish & Wildlife Service (USFWS).

ION's planned seismic survey incorporates both design features and operational procedures for minimizing the potential impacts on marine mammals and on subsistence hunts. Survey design features include:

- Scheduling the survey to occur in October–December in order to avoid periods of higher abundance of marine mammal species and most of the subsistence hunting activities that occur during the open-water season;
- Planning the survey to proceed from east to west across the US Beaufort Sea to avoid, as much as possible, any remaining migratory animals and associated subsistence activities; and
- Completing the survey prior the time when ringed seals would establish and enter lairs for reproductive purposes.

The potential disturbance of marine mammals during survey operations will be minimized further through the implementation of several ship-based mitigation measures when necessary. These include ramping up the airguns at the beginning of operations, and power-downs or shutdowns when marine mammals are detected within specified distances from the sound source. These distances have been determined using models of sound propagation from the planned airgun source described below.

The mitigation and monitoring measures described herein represent a combination of the procedures required by past IHAs for Arctic projects, plus additional measures that address the unique challenges associated with the early winter timing of the proposed survey. The following subsections provide more detailed information about the mitigation measures that are an integral part of the planned activity.

(a) Marine Mammal Monitoring

Vessel-based observers will monitor marine mammals near the seismic source vessel during all daytime airgun operations and during any nighttime start ups of the airguns. These observations will provide the real-time data needed to implement some of the key mitigation measures. When marine mammals are observed within, or about to enter, designated safety zones (see below) where there is a possibility of significant effects on hearing or other physical effects, airgun operations will be powered down (or shut down if necessary) immediately.

- During daylight, vessel-based observers will watch for marine mammals near the seismic vessel during all periods of seismic activity and for a minimum of 30 min prior to the planned start of airgun operations after an extended shut down.
- ION proposes to conduct nighttime as well as daytime operations. MMOs are not proposed to be on duty during ongoing seismic operations at night, given the very limited effectiveness of visual observation at night. At night, bridge personnel will watch for marine mammals (insofar as practical at night) and will call for the airguns to be shut down if marine mammals are observed in or about to enter the safety radii. If the airguns need to be started up at night, a MMO aboard the source vessel will monitor marine mammals near the source for 30 min prior to start up of the airguns using either floodlights or a night vision device (NVD), and a MMO aboard the icebreaker will monitor the area using a forward-looking infrared (FLIR) system, if the proper conditions for nighttime start up exist (see below).

Marine Mammal Observers

Vessel-based monitoring for marine mammals will be performed by trained MMOs throughout the period of survey activities to comply with expected provisions in the permits issued to ION. An experienced field crew leader will supervise the MMO teams onboard the vessels. The observers will monitor the occurrence and behavior of marine mammals near the survey vessel during all daylight periods while airguns are active, and during most daylight periods when airgun operations are not occurring. MMO duties will include watching for and identifying marine mammals; recording their numbers, distances, and reactions to the survey operations; and documenting “take by harassment” as defined by NMFS.

Number of Observers

Recent permits issued for seismic surveys in the Arctic have required that a sufficient number of MMOs be onboard the survey vessel to meet the following criteria:

- 100% monitoring coverage during all periods of airgun operations in daylight;
- maximum of 4 consecutive hours on watch per MMO;
- maximum of ~12 hours of watch time per day per MMO.

These previous surveys have typically been conducted at times with nearly 24 hrs of daylight and thus required four to five MMOs to be aboard the survey vessel. However, ION’s proposed survey will occur in October-December when the number of hours of daylight is significantly lower, and thus will require fewer MMOs to be aboard the survey vessel. MMOs aboard the icebreaker operating 0.5–1 km ahead of the survey vessel will provide early detection of marine mammals along the survey track. Three MMOs will be stationed aboard the icebreaker to take advantage of this forward operating platform and provide advanced notice of marine mammals to the MMO on the survey vessel. A single MMO will be stationed aboard the survey vessel to monitor the exclusion zones centered on the airguns and to request mitigation actions when necessary.

Observer Qualifications and Training

Crew leaders and most other biologists serving as observers will be individuals with recent experience as observers during one or more seismic monitoring projects in Alaska, the Canadian Beaufort, or other offshore areas.

Biologist-observers will have previous marine mammal observation experience, and field crew leaders will be highly experienced with previous vessel-based marine mammal monitoring and mitigation projects. Resumés for those individuals will be provided to NMFS and USFWS for review and acceptance of their qualifications. Inupiat observers will be experienced in the region, familiar with the marine mammals of the area, and complete a NMFS approved observer training course designed to familiarize individuals with monitoring and data collection procedures. A marine mammal observers' handbook, adapted for the specifics of the planned survey program will be prepared and distributed beforehand to all MMOs (see summary below).

Most observers, including Inupiat observers, will also complete a minimum two-day training and refresher session on marine mammal monitoring, to be conducted shortly before the anticipated start of the seismic survey. Any exceptions will have equivalent experience or training. The training session(s) will be conducted by qualified marine mammalogists with extensive crew-leader experience during previous vessel-based seismic monitoring programs.

Primary objectives of the training include:

- review of the marine mammal monitoring plan for this project, including any amendments specified by NMFS or USFWS in the IHA or LOA, by MMS, or by other agreements in which ION may elect to participate;
- review of marine mammal sighting, identification, and distance estimation methods;
- review of operation of specialized equipment (reticle binoculars, night vision devices, and GPS system);
- review of, and classroom practice with, data recording and data entry systems, including procedures for recording data on marine mammal sightings, monitoring operations, environmental conditions, and entry error control. These procedures will be implemented through use of a customized computer database and laptop computers;
- review of the specific tasks of the Inupiat Communicator.

MMO Handbook

A Marine Mammal Observers' Handbook will be prepared for IONs' monitoring program. Handbooks contain maps, illustrations, and photographs, as well as text, and are intended to provide guidance and reference information to trained individuals who will participate as MMOs. The following topics will be covered in the MMO Handbook for the ION project:

- summary overview descriptions of the project, marine mammals and underwater noise, the monitoring program, the NMFS IHA and USFWS LOA and other regulations/permits/agencies, the Marine Mammal Protection Act;
- monitoring and mitigation objectives and procedures, initial safety radii;
- responsibilities of staff and crew regarding the marine mammal monitoring plan;
- instructions for ship crew regarding the marine mammal monitoring plan;
- data recording procedures: codes and coding instructions, common coding mistakes, electronic database; navigational, marine physical, field data sheet;
- use of specialized field equipment (reticle binoculars, NVDs, FLIR cameras, laser rangefinders);
- reticle binocular distance scale;
- table of wind speed, Beaufort wind force, and sea state codes;
- data storage and backup procedures;
- list of species that might be encountered: identification, natural history;
- safety precautions while onboard;
- crew and/or personnel discord; conflict resolution among MMOs and crew;
- drug and alcohol policy and testing;
- scheduling of cruises and watches;

- communications;
- list of field gear that will be provided;
- suggested list of personal items to pack;
- suggested literature, or literature cited; and
- copies of the NMFS IHA and USFWS LOA when available.

The observer(s) will watch for marine mammals from the best available vantage point on the vessel, typically the bridge. The observer(s) will scan systematically with the unaided eye and 7×50 reticle binoculars, supplemented with 20×60 image-stabilized Zeiss Binoculars or Fujinon 25×150 "Big-eye" binoculars, a thermal imaging (FLIR) camera, and night-vision equipment when needed (see below). Personnel on the bridge will assist the marine mammal observer(s) in watching for marine mammals.

Information to be recorded by marine mammal observers will include the same types of information that were recorded during recent monitoring programs associated with Industry activity in the Arctic (e.g., Ireland et al. 2009). When a mammal sighting is made, the following information about the sighting will be recorded:

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

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

Distances to nearby marine mammals will be estimated with binoculars (Fujinon 7 × 50 binoculars) containing a reticle to measure the vertical angle of the line of sight to the animal relative to the horizon.

Observers may use a laser rangefinder to test and improve their abilities for visually estimating distances to objects in the water. However, previous experience has shown that a Class 1 eye-safe device was not able to measure distances to seals more than about 70 m away. The device was very useful in improving the distance estimation abilities of the observers at distances up to about 600 m—the maximum range at which the device could measure distances to highly reflective objects such as other vessels. Humans observing objects of more-or-less known size via a standard observation protocol, in this case from a standard height above water, quickly become able to estimate distances within about ±20% when given immediate feedback about actual distances during training.

When a marine mammal is seen within the safety radius applicable to that species, the geophysical crew will be notified immediately so that mitigation measures called for by the IHA and LoA can be implemented. It is expected that the airgun arrays will be shut down within several seconds—often before the next shot would be fired, and almost always before more than one additional shot is fired. The marine mammal observer will then maintain a watch to determine when the mammal(s) appear to be outside the safety zone such that airgun operations can resume.

Monitoring At Night and In Poor Visibility

Night-vision equipment ("Generation 3" binocular image intensifiers, or equivalent units) will be available for use when/if needed. Past experience with night-vision devices (NVDs) in the Beaufort Sea and elsewhere has indicated that NVDs are not nearly as effective as visual observation during daylight hours (e.g., Harris et al. 1997, 1998; Moulton and Lawson 2002). A forward looking thermal imaging (FLIR) camera system mounted on a high point in front of the icebreaker will also be available to assist with detecting the presence of seals and polar bears on ice and in water ahead of the airgun array.

Specialized Field Equipment

ION will provide or arrange for the following specialized field equipment for use by the onboard MMOs: 7×50 reticle binoculars, +20× binoculars, GPS unit, laptop computers, night vision binoculars, and possibly digital still and digital video cameras.

Field Data-Recording, Verification, Handling, and Security

The observers will record their observations onto datasheets or directly into handheld computers. During periods between watches and periods when operations are suspended, those data will be entered into a laptop computer running a custom computer database. The accuracy of the data entry will be verified in the field by computerized validity checks as the data are entered, and by subsequent manual checking of the database printouts. These procedures will allow initial summaries of data to be prepared during and shortly after the field season, and will facilitate transfer of the data to statistical, graphical or other programs for further processing. Quality control of the data will be facilitated by (1) the start-of-season training session, (2) subsequent supervision by the onboard field crew leader, and (3) ongoing data checks during the field season.

The data will be backed up regularly onto CDs and/or USB disks, and stored at separate locations on the vessel. If possible, data sheets will be photocopied daily during the field season. Data will be secured further by having data sheets and backup data CDs carried back to the Anchorage office during crew rotations.

Field Reports

Throughout the survey program, the observers will prepare a report each day or at such other interval as the IHA, LOA, or ION may require, summarizing the recent results of the monitoring program. The reports will summarize the species and numbers of marine mammals sighted. These reports will be provided to NMFS, USFWS and to the survey operators.

Reporting

The results of the vessel-based monitoring, including estimates of “take by harassment”, will be presented in the 90-day and final technical reports. Reporting will address the requirements established by USFWS in the LoA and NMFS in the IHA.

The technical report(s) will include:

- summaries of monitoring effort: total hours, total distances, and distribution of marine mammals through the study period accounting for sea state and other factors affecting visibility and detectability of marine mammals;
- methods, results, and interpretation pertaining to all acoustic characterization work and vessel-based monitoring;
- analyses of the effects of various factors influencing detectability of marine mammals including sea state, number of observers, and fog/glare;
- species composition, occurrence, and distribution of marine mammal sightings including date, water depth, numbers, age/size/gender categories, group sizes, and ice cover;
- analyses of the effects of survey operations:

- sighting rates of marine mammals during periods with and without airgun activities (and other variables that could affect detectability);
- initial sighting distances versus airgun activity state;
- closest point of approach versus airgun activity state;
- observed behaviors and types of movements versus airgun activity state;
- numbers of sightings/individuals seen versus airgun activity state;
- distribution around the survey vessel versus airgun activity state;
- estimates of "take by harassment".

(b) Proposed Safety Radii

Under current NMFS guidelines (NMFS 2000), "safety radii" for marine mammals around industrial sound sources are defined as the distances within which received sound levels are ≥180 dB re 1 µPa (rms) for cetaceans and ≥190 dB re 1 µPa (rms) for pinnipeds. These safety criteria are based on an assumption that sound energy received at lower received levels will not injure these animals or impair their hearing abilities, but that higher received levels might have some such effects. Disturbance or behavioral effects to marine mammals from underwater sound may occur after exposure to sound at distances greater than the safety radii (Richardson et al. 1995).

Received sound levels were modeled for the full 28 airgun, 4330 in^3 array in relation to distance and direction from the source (Zykov et al. 2010). Based on the model results, Table 1 shows the distances from the airguns where ION predicts that sound levels of 190, 180, and 160 dB re 1 µPa (rms) will be received. A single 65-in^3 airgun will be used as a mitigation gun during turns or if a power down of the full array is necessary due to the presence of a marine mammal within or about to enter the applicable safety radius of the full airgun array. Underwater sound propagation of a 40-in^3 airgun was measured near Harrison Bay in 2007 and results were reported in Funk et al. (2009). The 190 dB and 180 dB distances from those measurements, 5 m and 20 m respectively, multiplied by 2 (10 m and 40 m, respectively) will be used as the safety zones during use of the single 65 in^3 airgun until results from field measurements are available.

TABLE 1. Distances to which sound is estimated to propagate by water depth and received sound level.

Received sound level (dB re 1 µPa rms)	**Water depth (m)**		
	<100	**100–1000**	**>1000**
190	670	215	215
180	2850	750	675
160	26,700	27,600	31,600

ION plans to measure received sound levels as a function of distance from the array prior to or early during the survey in the east Beaufort Sea. Those data will be modeled together with data from past sound source measurements completed in the Alaskan Beaufort Sea with similar arrays to estimate appropriate safety radii for use during the survey.

Airguns will be powered down (or shut down if necessary) immediately when marine mammals are detected within or about to enter the applicable ≥180 or ≥190 dB (rms) radius as described further below.

(c) Mitigation during Operations

In addition to monitoring, mitigation measures that will be adopted will include (1) design of the survey to occur during periods of low marine mammal density to minimize encounters, (2) speed or course alteration, provided that doing so will not compromise operational safety requirements, (3) power down or shut-down procedures, and (4) no start up of airgun operations unless the 180 dB safety zone is visible for at least 30 min during day or night.

Other proposed provisions associated with operations at night or in periods of poor visibility include the following:

- During foggy conditions or darkness the full 180 dB (rms) safety radius may not be visible. In that case, the airguns could not start up after a full shut down until the entire 180 dB radius was visible.
- During any nighttime operations, if the 180 dB safety radius is visible using vessel lights, NVDs[1] and/or FLIR, then start up of the airgun array may occur following a 30-min period of observation without sighting marine mammals in the safety radius.
- If one or more airguns have been operational before nightfall, they can remain operational throughout the night, even though the entire safety radius may not be visible.

Speed or Course Alteration

If a marine mammal (in water) is detected outside the safety radius and, based on its position and the relative motion, is likely to enter the safety radius, the vessel's speed and/or direct course may, when practical and safe, be changed in a manner that also minimizes the effect on the planned objectives. The marine mammal activities and movements relative to the seismic vessel will be closely monitored to ensure that the marine mammal does not approach within the safety radius. If the mammal appears likely to enter the safety radius, further mitigative actions will be taken, i.e., either further course alterations or power down or shut down of the airgun(s).

Power-down Procedures

A power down involves decreasing the number of airguns in use such that the radii of the 190 dB (rms) and 180 dB (rms) zones are decreased to the extent that observed marine mammals are not in the applicable safety zone. A power down may also occur when the vessel is moving from one seismic line to another. During a power down, one airgun (or some other number of airguns less than the full airgun array) is operated. The continued operation of one airgun is intended to (a) alert marine mammals to the presence of the seismic vessel in the area, and (b) retain the option of initiating a ramp up to full operations under poor visibility conditions. In contrast, a shut down occurs when all airgun activity is suspended.

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[1] See Smultea and Holst (2003), Holst (2004), Smultea et al. (2004), and Stoltz and MacLean *in* MacLean and Koski (2005) for an evaluation of the effectiveness of night vision equipment for nighttime marine mammal observations.

If a marine mammal is detected outside the safety radius but is likely to enter the safety radius, and if the vessel's speed and/or course cannot be changed to avoid having the mammal enter the safety radius, the airguns may (as an alternative to a complete shut down) be powered down before the mammal is within the safety radius. Likewise, if a mammal is already within the safety zone when first detected, the airguns will be powered down immediately if this is a reasonable alternative to a complete shut down. During a power down of the array, the number of guns operating will be reduced to a single 65 in^3 airgun. The 190 dB (rms) safety radius around the power down source has not yet been estimated, but will be estimated before the field season and verified during acoustic verification measurements made at the start of seismic operations. If a marine mammal is detected within or near the smaller safety radius around the single 65 in^3 airgun, all airguns will be shut down (see next subsection).

Following a power down, operation of the full airgun array will not resume until the marine mammal has cleared the safety zone. The animal will be considered to have cleared the safety zone if it

- is visually observed to have left the safety zone, or
- has not been seen within the zone for 15 min in the case of pinnipeds or small odontocetes, or
- has not been seen within the zone for 30 min in the case of mysticetes (large odontocetes do not occur within the study area).

Shut-down Procedures

The operating airgun(s) will be shut down completely if a marine mammal approaches or enters the then-applicable safety radius and a power down is not practical or adequate to reduce exposure to less than 190 or 180 dB (rms), as appropriate. The operating airgun(s) will also be shut down completely if a marine mammal approaches or enters the estimated safety radius around the reduced source (one 65 in^3 airgun) that will be used during a power down.

Airgun activity will not resume until the marine mammal has cleared the safety radius. The animal will be considered to have cleared the safety radius if it is visually observed to have left the safety radius, or if it has not been seen within the radius for 15 min (pinnipeds) or 30 min (mysticetes). Ramp-up procedures will be followed during resumption of full seismic operations after a shut-down of the airgun array.

Ramp-up Procedures

A ramp up of an airgun array provides a gradual increase in sound levels, and involves a step-wise increase in the number and total volume of airguns firing until the full volume is achieved. The purpose of a ramp up (or “soft start”) is to “warn” marine mammals in the vicinity of the airguns and to provide the time for them to leave the area and thus avoid any potential injury or impairment of their hearing abilities.

NMFS normally requires that, once ramp up commences, the rate of ramp up be no more than 6 dB per 5 min period. Ramp up will likely begin with a single airgun (the smallest airgun in the array). The precise ramp-up procedure has yet to be determined, but ION intends to follow NMFS’ guideline (or whatever guideline USFWS adopts) with a ramp up rate of no more than 6 dB per 5 min period. A common procedure to achieve this rate is to double the number of operating airguns at 5-min intervals. During the ramp-up, the safety zone for the full array will be maintained.

A full ramp up, after a shut down, will not begin until there has been a minimum of 30 min of observation of the safety zone by MMOs to assure that no marine mammals are present. The entire safety zone must be visible during the 30-minute lead-in to a full ramp up. If the entire safety zone is not visible, then ramp up from a cold start cannot begin. If a marine mammal(s) is sighted within the safety zone during the 30-minute watch prior to ramp up, ramp up will be delayed until the marine mammal(s) is sighted outside of the safety zone or the animal(s) is not sighted for at least 15 minutes.

A ramp up procedure will be followed when the airgun array begins operating after a specified-duration period with no or reduced airgun operations. The minimum duration of a shut-down period, i.e., without airguns firing, which must be followed by a ramp up typically is the amount of time it would take the source vessel to cover the 180-dB safety radius. The actual time period depends on ship speed and the size of the 180-dB safety radius. We estimate that period to be about 5 minutes in intermediate (100-1000 m) and deep (>1000 m) waters, and ~23 min in shallow waters (<100 m) based on the airgun array modeling results (Zykov et al. 2010) and a survey speed of 4 kts.

During turns and transit between seismic transects, at least one airgun will remain operational. The ramp-up procedure will still be followed when increasing the source levels from one air gun to the full arrays. However, keeping one airgun firing will avoid the prohibition of a cold start during darkness or other periods of poor visibility on the assumption that marine mammals will be alerted by the sounds from the single airgun and can move away. Given the responsiveness of bowhead and beluga whales to airgun sounds, it can be assumed that those species in particular will move away during a ramp up. Through use of this approach, seismic operations can resume upon entry to a new transect without a full ramp up and the associated 30-minute lead-in observations. MMOs will be on duty whenever the airguns are firing during daylight, and during the 30-min periods prior to ramp-ups as well as during ramp-ups. Daylight will occur for ~11 h/day at the start of the survey in early October diminishing to ~3 h/day in mid November. MMOs will be called up at night to observe prior to and during any ramp up. The seismic operator and MMOs will maintain records of the times when ramp-ups start, and when the airgun arrays reach full power.

Alternative Action: Another Time

An alternative to issuing the IHA and conducting the survey during the period requested is to issue the IHA and conduct the survey during a different time period. However, one of the most effective measures to minimize impacts on marine mammals from seismic operations is to perform these activities during a period when few marine mammal species and individuals are present in the area. ION plans to conduct seismic operations during October–December when the majority of whales are migrating west and southward to their wintering grounds and are expected to be present only in low numbers. Conducting operations earlier than proposed could be impractical and could result in more marine mammals being exposed to seismic noise.

A major scheduling consideration for the proposed seismic survey relates to the timing of the subsistence hunt by Alaskan Natives. Fall whaling activities begin in Kaktovik around late August or early September and the whaling season generally progresses on later dates at Nuiqsut and Barrow as the bowhead migration progresses westward across the US Beaufort Sea. The latest fall whaling occurs at Barrow from late September into October. The proposed survey takes place outside the Kaktovik and Nuiqsut fall bowhead hunting season. However, there is potential to impact the bowhead fall hunt in Barrow. Both vessels will communicate with the whaling communities prior to approaching Barrow (or any other village) and coordinate their activities with those of whalers to eliminate any potential disturbance to ongoing whaling activities. The plan to conduct the survey working from east to west across the Beaufort Sea is intended to avoid or limit any operations in regions where bowhead subsistence hunting may occur. Hunts for seals and polar bears might also take place during the early winter, but these hunting efforts are opportunistic and typically do not ocurr until after the requested timing of the survey.

The overall schedule for the *Geo Explorer* and the accompanying vessel has been established to accomplish this cruise and other objectives in a coordinated and optimized manner. The personnel and specialized equipment to be deployed on the *Geo Explorer* and the accompanying vessel are available for the planned period but not necessarily for other periods. Issuance of the IHA for a substantially different range of dates would require changes in scheduling of personnel and equipment which could result in cancellation of the 2010 cruise, given the probable inability to amend the schedules for all of the required project components.

No Action Alternative

An alternative to conducting the proposed activities is the "No Action" alternative, i.e., the proposed geophysical survey will not be conducted. If the survey were not conducted, the "No Action" alternative would result in no disturbance to marine mammals attributable to the proposed seismic activities. Likewise, there would then be no possibility of effects on seabirds, fisheries or on accessibility of marine mammals for subsistence hunting. However, there would be little reduction in impacts if the project did not go ahead, given the negligible effects on marine mammals, subsistence hunting, seabirds and fisheries that are anticipated if the project goes ahead as planned.

III. AFFECTED ENVIRONMENT

Physical Environment

The Arctic region contains 12 of the world's Large Marine Ecosystems (LME): West Greenland Shelf, East Greenland Shelf, Barents Sea, Norwegian Shelf, West Bering Sea, Chukchi Sea, Beaufort Sea, East Siberian Sea, Laptev Sea, Kara Sea, Hudson Bay, and Arctic Ocean (UN Atlas of the Oceans n.d.). Of these 12 LMEs, the proposed project will be active primarily within the Beaufort Sea LME and to a lesser extent in the Chukchi Sea LME.

The Beaufort Sea LME is a high-latitude marine region off the coast of northern Alaska and northwest Canada; it is dominated by an extreme arctic climate (UN Atlas of the Oceans n.d.). Water depths are shallow in nearshore areas and gradually increase along the continental shelf and slope and into the abyssal plain where depths reach several thousand meters. Most of the Beaufort Sea is ice-covered for the majority of the year, although there are major seasonal and annual variations. The Beaufort Gyral Stream forms a clockwise drift pattern. Leads can occur north of Barrow at any time of year, and in that area there are varying amounts of open water from late spring through autumn. During October–December, the majority of the proposed study area will likely be covered by first-year ice.

A small portion of the proposed geophysical survey will occur in the northern Chukchi Sea LME. In contrast to the Beaufort Sea, the Chukchi Sea has a relatively shallow, uniform seafloor with depths generally <50 m.

Biological Environment

The Beaufort Sea and Chukchi Sea LMEs experience highly variable seasonal productivity (UN Atlas of the Oceans n.d.). During winter light penetration is limited due to low light conditions and the extent of sea-ice cover. Increasing daylight in the summer results in warmer temperatures, ice melt and significantly higher productivity. The coastal region supports a wide diversity of organisms providing habitat for ducks, geese, swans, shorebirds and marine birds. Many species of birds and fish rely on river deltas, estuaries, spits, lagoons and islands in coastal waters for breeding habitat, food, shelter, and brood-rearing. Various waterbird and fish species depend on marine waters (mainly over the continental shelf) for food and habitat during the summer. Marine mammals are also relatively diverse in the Beaufort Sea and Chukchi Sea LMEs.

Fish Resources

Fisheries

FishBase, a global information system on fishes available at fishbase.org (Froese and Pauly 2009), lists 102 marine fish species as being present in the Beaufort Sea LME (Appendix A) and 82 fish species for the Chukchi Sea LME (Appendix B). The majority of the fisheries in the Beaufort Sea and Chukchi Sea LMEs are of a subsistence nature and are conducted close to shore. There is no fishing activity along the planned geophysical survey route.

Twenty-one species of fish are harvested commercially in the Beaufort Sea, including arctic cisco (*Coregonus autumnalis*), broad whitefish (*C. nasus*), least cisco (*C. sardinella*), and Dolly Varden char (*Salvelinus malma*). Several species (including the Dolly Varden char) are anadromous and move seasonally between fresh water and underground springs in winter and salt water in summer.

These fish, however, remain in the coastal waters and it is unlikely that they will be farther offshore in the study area. These species have adapted to arctic conditions through complex migration patterns, late maturity and low recruitment rates.

Subsistence fishing occurs in the Barrow and Colville River delta areas but not in the proposed survey area. A small commercial fishery operates in the Colville River delta, >115 km southeast of the closest survey line. No large fisheries are operated in the Alaskan Beaufort Sea or the northern Chukchi Sea.

Essential Fish Habitat

The Magnuson-Stevens Fishery Conservation and Management Act (MSA; 16 U.S.C. §1801-1882) established Regional Fishery Management Councils and mandated that Fishery Management Plans (FMPs) be developed to manage exploited fish and invertebrate species responsibly in Federal waters of the U.S. In 1996 as the Sustainable Fisheries Act amended the MSA to require the description and identification of Essential Fish Habitat (EFH) and FMPs, adverse impacts on EFH, and actions to conserve and enhance EFH. Guidelines were developed by NMFS to assist fishery management councils in fulfilling the requirements set forth by the MSA.

The North Pacific Fisheries Management council (NPFMC) was tasked with preparation of a FMP for the Arctic Management Area which includes all marine waters in the U.S. Exclusive Economic Zone of the Chukchi and Beaufort seas from three nautical miles offshore of the Alaska coast to 200 n.mi offshore. The FMP was approved by the Secretary of Commerce in August 2009 and governs commercial fishing for all stocks of fish including all finfish, shellfish, or other marine living resources, except commercial fishing for Pacific salmon and Pacific halibut. EFH established in the FMP includes all waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity. Identification of EFH is based on the historical range of target species but may expand or contract based on a variety of factors including changes in environmental variables, population size, and predator/prey distribution. EFH may be specific to a specific life stage such as egg, larval, juvenile, etc. EFH is described for only one target species, arctic cod (*Boreogadus saida*), that is likely to occur in the proposed survey area (NPFMC 2009).

Seabirds

Two bird species of special concern may be encountered during transits off the coast of Alaska. Spectacled eiders (*Somateria fischeri*) travel west along the arctic coast after breeding across the Arctic Coastal Plain (ACP) of northern Alaska. Both marine and terrestrial (for males in particular) routes are used during migration (Troy 2003). Steller's eiders (*Polysticta stelleri*) also breed on the ACP and move to marine habitats after breeding (Fredrichson 2001), but occur in much lower densities than spectacled eiders and would be less likely to be encountered by transiting vessels in the southern Beaufort Sea. Spectacled and Steller's eiders were listed as threatened in the U.S. under the ESA in May 1993 and July 1997, respectively. The USFWS developed separate Recovery Plans for each species (USFWS 1996, 2002).

(1) Spectacled Eider

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

The North Slope spectacled eider population seems to be stable, at least since the initiation of aerial surveys of the ACP since 1992 (Larned et al. 2009).

Spectacled eiders breed in low densities across the Alaskan Arctic Coastal Plain (ACP) east to about the Shaviovik River. Males leave the breeding grounds along the ACP around mid- to late June at the onset of incubation by female eiders. Males are followed by females whose nests fail, and finally by successful breeding females and young birds in August and September. Female spectacled eiders have been documented migrating west along the Alaska coast as far as 40 km offshore (TERA 1999). Large concentrations of spectacled eiders gather in Ledyard Bay in the eastern Chukchi Sea after the breeding season to feed and molt before moving to the Bering Sea wintering grounds. Ledyard Bay is located between Icy Cape and Cape Lisburne and was designated as the Ledyard Bay Critical Habitat Unit (LBCHU) by the USFWS in 2001.

The proposed 2010 geophysical activities will occur primarily in the Beaufort Sea beginning ~1 October. Most spectacled eiders will have migrated from the Beaufort Sea by that time although small numbers of spectacled eiders could be encountered in nearshore locations of the proposed survey area. The *Geo Explorer* and *Vladimir Ignatyuk* could encounter spectacled eiders during the transit through the Chukchi Sea after completion of the survey activities, however most if not all spectacled eiders will have departed the Chukchi Sea by late October.

Activities associated with the proposed geophysical survey are not likely to affect spectacled eiders or other marine birds. The primary concern relates to the potential for bird collisions with vessels which could result in injury or mortality. Spectacled eiders and other marine birds can easily avoid oncoming vessels and in general there is little potential for impacts to marine birds to result from the proposed activities. Spectacled eiders are unlikely to occur in the proposed survey area during the survey period and impacts will likely be negligible.

(2) Steller's Eider

Most Steller's eiders breed across coastal eastern Siberia and a small number breed on the ACP of Alaska, most conspicuously near Barrow. A smaller population also breeds in western Russia and winters in northern Europe (Fredrichson 2001). Steller's eiders were formerly common breeders in the Y-K delta, but numbers there declined drastically and Steller's eider is now apparently rare as a breeding species on the Y-K delta (Kertell 1991; Flint and Herzog 1999). Steller's eider density on the ACP is low with the highest densities reported near Barrow. The largest population, located in eastern Russia, may number >128,000 birds (Hodges and Eldridge 2001).

Steller's eiders have been observed east of Barrow to the Prudhoe Bay area where they are considered rare (TERA 1997). Although Steller's eiders may breed in a relatively large area of the ACP as far east as the Prudhoe Bay area, densities are low. Steller's eiders apparently do not breed every year and breeding may be tied to the lemming cycle (Quakenbush et al. 2004).

After the breeding season Steller's eiders move to marine habitats and may use lagoon systems and coastal bays from Barrow to Cape Lisburne, the northeast Chukotka coast, and numerous locations in southwest Alaska (USFWS 2007). Few if any Steller's eiders would likely be encountered during proposed geophysical survey activities in the southern Beaufort or Chukchi seas or during transit through the Chukchi Sea after completion of the proposed survey.

(3) Other Seabirds, Shorebirds, and Waterfowl

In addition to the two eider species described above, a portion of the project area is within the range of a number of other seabird, shorebird, and waterfowl species. Most of these species would be found mainly within 30 km of shore. Summer bird densities in offshore marine waters of the Beaufort Sea are considered to be lower than in other marine areas adjacent to Alaska (U.S. Army Corps of Engineers 1999). There is a general absence of diving seabirds in the offshore waters of the southern Beaufort Sea, with the exception of small numbers of thick-billed murres (*Uria lomvia*), horned puffins (*Fratercula corniculata*), loons (*Gavia* spp.) and black guillemots (*Cepphus grylle*). A few species of surface-feeding birds also make use of offshore waters, including red and red-necked phalaropes (*Phalaropus fulicaria* and *P. lobatus*), pomarine, parasitic and long-tailed jaegers (*Stercorarius pomarinus*, *S. parasiticus, and S. longicaudus*), arctic tern (*Sterna paradisaea*), and glaucous gulls (*Larus hyperboreus*). Divoky (1979) reported a bird density during the open-water season in offshore waters deeper than 18 m (60 feet) of less than 10 birds/km^2.

Divoky (1983) conducted extensive boat-based surveys in the Beaufort Sea during early August through mid-September. The primary species observed during pelagic surveys were surface-feeding species including gulls, terns, phalaropes, and jaegers. Long-tailed ducks, loons, and migrant eiders as well as low densities of surface-feeding species were reported during nearshore surveys. Pelagic birds were feeding primarily on arctic cod while nearshore birds were feeding on epibenthic crustaceans and zooplankton.

Frame (1973) conducted seabird observations from an icebreaker in the Beaufort Sea during August 1969 and reported black-legged kittiwake (*Rissa tridactyla*) as the most abundant species, followed by Sabine's gull (*Xema sabini*). Pomarine and long-tailed jaegers were the other two most commonly observed species along with unidentified shorebirds.

Fisher and Larned (2004) conducted more recent aerial surveys of marine birds in 1999 and 2000 in areas to 100 km offshore of the Alaskan Beaufort Sea. Approximately 90% of birds observed were sea ducks, primarily long-tailed ducks (*Clangula hyemalis*), king eiders (*Somateria spectabilis*) and scoters (*Melanitta* sp.). Densities of most species decrease with distance offshore although king eiders densities were higher in deeper, offshore waters.

Harwood et al. (2005) recorded the distribution of birds during oceanographic studies through the Canadian Basin, Beaufort Sea, and Chukchi Sea from 16 August through 6 October 2002. Sixteen bird species and a total of 1213 individuals were recorded. The birds were found in greater density in areas where oceanographic features such as a shelf break, or an area of coastal upwelling, heightened productivity.

Marine Mammals

The marine mammals that occur in the proposed survey area belong to three taxonomic groups: odontocetes (toothed cetaceans, such as beluga whale and narwhal whale), mysticetes (baleen whales), and carnivora (pinnipeds and polar bears). Cetaceans and pinnipeds (except walrus) are managed by the NMFS; Pacific walrus and polar bear are managed by the USFWS.

A total of nine cetacean species, five species of pinnipeds, and one ursid (polar bear) are known to or may occur in or near the proposed study area (Table 2). Three of these species, the bowhead, humpback, and fin whales, are listed as endangered under the ESA. Humpback and fin whales however, are unlikely to be encountered during the survey period.

The marine mammal species most likely to be encountered during the seismic survey include two cetacean species (beluga whale and bowhead whale), two pinniped species (ringed and bearded seals), and polar bear. However, most species will occur in low numbers and encounters are likely to be most common within 100 km of shore. The marine mammal most likely to be encountered throughout the cruise is ringed seal. The most widely distributed marine mammals within the proposed survey area are expected to be the beluga whale, ringed seal, and polar bear.

Seven additional cetacean species— narwhal, killer whale, harbor porpoise, gray whale, minke whale, fin whale, and humpback whale —could occur in the project area. However, due to the early winter timing of the proposed survey, occurrence of these species during the survey period is unlikely. Gray whale occurs regularly in continental shelf waters along the Chukchi Sea coast in summer and to a lesser extent along the Beaufort Sea coast. Recent evidence from monitoring activities in the Chukchi and Beaufort seas during industry seismic surveys suggests that harbor porpoise and minke whale, which have been considered uncommon or rare in the Chukchi and Beaufort seas, may be increasing in numbers in these areas (Funk et al. 2009). Small numbers of killer whales have also been recorded during these industry surveys, along with a few sightings of fin and humpback whales. The narwhal occurs in Canadian waters and occasionally in the Beaufort Sea, but is rare there and not expected to be encountered. Each of these species is uncommon or rare in the Chukchi and Beaufort seas, and relatively few, if any, encounters with these species are expected during the seismic program.

Additional pinniped species that could be encountered during the proposed geophysical survey include spotted and ribbon seals, and Pacific walrus. Spotted seals are more abundant in the Chukchi Sea and occur in small numbers in the Beaufort Sea. Ribbon seal is uncommon in the Chukchi Sea and there are few sightings in the Beaufort Sea. Pacific walrus is common in the Chukchi Sea but uncommon in the Beaufort Sea. None of these species would likely be encountered during the proposed cruise other than perhaps during transit periods from the survey area.

Polar bears occur on the pack and shorefast ice, and on barrier islands. Polar bears have been recorded during recent vessel-based seismic surveys in the Beaufort Sea (Savarese et al. 2009) and may be encountered during the proposed geophysical survey.

TABLE 2. The habitat, abundance (in Alaska or the Beaufort Sea if available), and conservation status of marine mammals inhabiting the proposed survey area.

Species	Habitat	Abundance	ESA[1]	IUCN[2]	CITES[3]
Odontocetes Beluga whale (*Delphinapterus leucas*) (Eastern Chukchi Sea Stock)	Offshore, Coastal, Ice edges	3710[4]	Not listed	VU	II
Beluga whale (Beaufort Sea Stock)	Offshore, Coastal, Ice edges	39,257[5]	Not listed	VU	II
Narwhal (*Monodon monoceros*)	Offshore, Ice edge	Rare[6]	Not listed	DD	II
Killer whale (*Orcinus orca*)	Widely distributed	Rare	Not listed	LR-cd	II
Harbor Porpoise (*Phocoena phocoena*) (Bering Sea Stock)	Coastal, inland waters, shallow offshore waters	Uncommon	Not listed	VU	II
Mysticetes Bowhead whale (*Balaena mysticetus*)	Pack ice & coastal	11,800[7]	Endangered	LR-cd	I
Gray whale (*Eschrichtius robustus*) (eastern Pacific population)	Coastal, lagoons	Uncommon	Not listed	LR-cd	I
Fin whale (*Balaenoptera physalus*)	Slope, mostly pelagic	Rare (Chukchi)	Endangered	EN	I
Minke whale (*Balaenoptera acutorostrata*)	Shelf, coastal	Rare	Not listed	LR-cd	I
Humpback whale (*Megaptera novaeangliae*)	Shelf, coastal	Rare	Endangered	LR-lc	I
Pinnipeds Bearded seal (*Erignathus barbatus*)	Pack ice, shallow offshore waters	300,000-450,000[8] 4863[9]	In review for listing	–	–
Spotted seal (*Phoca largha*)	Pack ice, coastal haulouts	~59,214[10] 1000[10]	Arctic pop. segments not listed	–	–
Ringed seal (*Pusa hispida*)	Landfast & pack ice, offshore	18,000 [11] ~208,000-252,000[12]	In review for listing	–	–
Ribbon seal (*Histriophoca fasciata*)	Offshore, pack ice	Rare	Not LIsted	–	–
Pacific Walrus (*Odobenus rosmarus*)	Coastal, Pack ice, ice floes	~200,000 to 246,000[13]	In review for listing	–	II

Species	Habitat	Abundance	ESA[1]	IUCN[2]	CITES[3]
Ursids Polar Bear (*Ursus maritimus*)	Pack ice	4700[14]	Threatened	–	–

[1] U.S. Endangered Species Act.

[2] IUCN Red List of Threatened Species (2003). Codes for IUCN classifications: CR = Critically Endangered; EN = Endangered; VU = Vulnerable; LR = Lower Risk (-cd = Conservation Dependent; -nt = Near Threatened; -lc = Least Concern); DD = Data Deficient.

[3] Convention on International Trade in Endangered Species of Wild Fauna and Flora (UNEP-WCMC 2004). Appendix I = endangered/threatened; Appendix II = threatened/at risk; Appendix III = some restrictions on trade of animals/animal parts.

[4] Angliss and Allen (2009)

[5] Beaufort Sea population (IWC 2000, Angliss and Allen 2009).

[6] Population in Baffin Bay and the Canadian arctic archipelago is ~60,000 (DFO 2004); very few enter the Beaufort Sea.

[7] 2004 Population estimate (Koski et al. 2009).

[8] Alaska population (USDI/MMS 1996).

[9] Eastern Chukchi Sea population (NMML, unpublished data).

[10] Alaska stock based on aerial surveys in 1992 (Angliss and Allen 2009).

[11] Beaufort Sea minimum estimate with no correction factor based on aerial surveys in 1996-1999 (Frost et al. 2002 *in* Angliss and Allen 2009).

[12] Eastern Chukchi Sea population (Bengtson et al. 2005)

[13] Pacific walrus population, 1975-1990 (Angliss and Allen 2009).

[14] Chukchi Sea and northern and southern Beaufort Sea populations combined (Aars et al. 2006; USFWS 2008).

(1) Odontocetes

(a) Beluga (*Delphinapterus leucas*)

Beluga whale is an arctic and subarctic species that includes several populations in Alaska and northern European waters. It has a circumpolar distribution in the Northern Hemisphere and occurs between 50º and 80ºN (Reeves et al. 2002). It is distributed in seasonally ice-covered seas and migrates to warmer coastal estuaries, bays, and rivers in summer for molting (Finley 1982).

Pod structure in beluga groups appears to be along matrilineal lines, with males forming separate aggregations. Small groups are often observed traveling or resting together. Belugas often migrate in groups of 100 to 600 animals (Braham and Krogman 1977) or more. The relationships between whales within groups are not known, although hunters have reported that belugas form family groups with whales of different ages traveling together (Huntington 2000).

In Alaska, beluga whales comprise five distinct stocks: Beaufort Sea, eastern Chukchi Sea, eastern Bering Sea, Bristol Bay, and Cook Inlet (O'Corry-Crowe et al. 1997). For the proposed project, only animals from the Beaufort Sea stock and eastern Chukchi Sea stock may be encountered. Some eastern Chukchi Sea animals enter the Beaufort Sea in late summer (Suydam et al. 2005).

The ***Beaufort Sea population*** was estimated to contain 39,258 individuals as of 1992 (DeMaster 1995; Angliss and Allen 2009). This estimate was based on the application of a sightability correction factor of 2× to the 1992 uncorrected census of 19,629 individuals made by Harwood et al. (1996). This estimate was obtained from a partial survey of the known range of the Beaufort Sea population and may be an underestimate of the true population size. This population is not considered by NMFS to be a strategic stock and is believed to be stable or increasing (Angliss and Allen 2009).

Beluga whales of the Beaufort stock winter in the Bering Sea, summer in the eastern Beaufort Sea, and migrate through offshore waters of western and northern Alaska (Angliss and Allen 2009). The majority of belugas in the Beaufort stock migrate into the Beaufort Sea in April or May, although some whales may pass Point Barrow as early as late March and as late as July (Braham et al. 1984; Ljungblad et al. 1984; Richardson et al. 1995a).

Much of the Beaufort Sea seasonal population enters the Mackenzie River estuary for a short period during July–August to molt their epidermis, but they spend most of the summer in offshore waters of the eastern Beaufort Sea, Amundsen Gulf and more northerly areas (Davis and Evans 1982; Harwood et al. 1996; Richard et al. 2001). Belugas are rarely seen in the central Alaskan Beaufort Sea during the early summer, but a number were reported there during early July from aerial surveys in 2008 (Christie et al. 2009). During late summer and autumn, most belugas migrate westward far offshore near the pack ice (Frost et al. 1988; Hazard 1988; Clarke et al. 1993; Miller et al. 1999). During fall aerial surveys in the Alaskan Beaufort Sea, Christie et al. (2009) reported the highest beluga sighting rates during the first two weeks of September and in the northern part of their survey area.

Moore (2000a) and Moore et al. (2000b) suggested that beluga whales select deeper water at or beyond the shelf break independent of ice cover. However, during the westward migration in late summer and autumn, small numbers of belugas are sometimes seen near the north coast of Alaska (e.g., Johnson 1979). Christie et al. (2009) reported higher beluga sighting rates at locations >60 km offshore than at locations nearer shore during aerial surveys in the Alaskan Beaufort Sea in 2006-2008. Belugas were not recorded, however, during arctic cruises by the *Healy* in 2005 or 2006 (Haley 2006; Haley and Ireland 2006). The main fall migration corridor of beluga whales is ~100+ km north of the coast. Satellite-linked telemetry data show that some belugas of this population migrate west considerably farther offshore, as far north as 76º to 78ºN latitude (Richard et al. 1997, 2001), which would be well beyond the range of the proposed survey. It is possible that beluga whales from the Beaufort Sea population could be encountered during the proposed survey, but most of these whales will have migrated into the Chukchi Sea by the time the vessels reach the western Beaufort Sea.

The ***eastern Chukchi Sea*** population is estimated at 3,710 animals (Angliss and Allen 2009). This estimate was based on surveys conducted in 1989–1991. Survey effort was concentrated on the 170-km long Kasegaluk Lagoon where belugas are known to occur during the open-water season. The calculation was considered to be a minimum population estimate for the eastern Chukchi Sea stock because the surveys on which it was based did not include offshore areas where belugas are also likely to occur. This population is considered to be stable. It is assumed that beluga whales from the eastern Chukchi stock winter in the Bering Sea (Angliss and Allen 2009).

Although beluga whales are known to congregate in Kasegaluk Lagoon during summer, evidence from a small number of satellite-tagged animals suggests that some of these whales may subsequently range into the Arctic Ocean north of the Beaufort Sea. Suydam et al. (2005) put satellite tags on 23 beluga whales captured in Kasegaluk Lagoon in late June and early July 1998–2002. Five of these whales moved far into the Arctic Ocean and into the pack ice to 79–80°N. These and other whales moved to areas as far as 1,100 km offshore between Barrow and the Mackenzie River delta spending time in water with 90% ice coverage.

During aerial surveys in nearshore areas (i.e., ~37 km offshore) of the Chukchi Sea in 2006–2008, peak beluga sighting rates were recorded in July and the lowest monthly sighting rates were recorded in September (Thomas et al. 2009). Sighting rates tended to increase in October and November. Beluga whale sighting rates and number of individuals were generally highest in the band 25–35 km offshore. The largest single groups, however, were sighted at locations near shore in the band within 5 km of shore.

It is possible that belugas from the eastern Chukchi Sea stock would be encountered if they migrated into the Beaufort Sea late in the summer and migrated south during the fall or early winter period. Most of the belugas in this stock are not expected to be in the survey area during October–December.

(b) Narwhal (*Monodon monoceros*)

Narwhals have a discontinuous arctic distribution (Hay and Mansfield 1989; Reeves et al. 2002). A large population inhabits Baffin Bay, West Greenland, and the eastern part of the Canadian Arctic archipelago, and much smaller numbers inhabit the Northeast Atlantic/East Greenland area. Population estimates for the narwhal are scarce, and the IUCN-World Conservation Union lists the species as Data Deficient (IUCN Red List of Threatened Species 2003). Innes et al. (2002) estimated a population size of 45,358 narwhals in the Canadian Arctic although little of the area was surveyed. There are scattered records of narwhal in Alaskan waters where the species is considered extralimital (Reeves et al. 2002). Thus, it is possible, but unlikely, that individuals could be encountered in the proposed survey area.

(c) Killer Whale (*Orcinus orca*)

Killer whales are cosmopolitan and globally fairly abundant. The killer whale is very common in temperate waters, but it also frequents the tropics and waters at high latitudes. Killer whales appear to prefer coastal areas, but are also known to occur in deep water (Dahlheim and Heyning 1999). The greatest abundance is thought to occur within 800 km of major continents (Mitchell 1975) and the highest densities occur in areas with abundant prey. Both resident and transient stocks have been described. The resident and transient types are believed to differ in several aspects of morphology, ecology, and behavior including dorsal fin shape, saddle patch shape, pod size, home range size, diet, travel routes, dive duration, and social integrity of pods (Angliss and Allen 2009).

Killer whales are known to inhabit almost all coastal waters of Alaska, extending from southeast Alaska through the Aleutian Islands to the Bering and Chukchi seas (Angliss and Allen 2009). Killer whales probably do not occur regularly in the Beaufort Sea although sightings have been reported (Leatherwood et al. 1986; Lowry et al. 1987). George et al. (1994) reported that they and local hunters see a few killer whales at Point Barrow each year. Killer whales are more common southwest of Barrow in the southern Chukchi Sea and the Bering Sea. Based on photographic techniques, ~100 animals have been identified in the Bering Sea (ADFG 1994). Killer whales from either the North Pacific resident or transient stock could occur in the Chukchi Sea during the summer, however winter occurrence is more unlikely. Marine mammal observers (MMOs) onboard industry vessels in the Chukchi Sea during summer and fall recorded two killer whale sightings each in 2006 and 2008, and one sighting in 2007 (Haley et al. 2009). MMOs onboard industry vessels did not record any killer whale sighting in the Beaufort Sea in 2006–2008 (Savarese et al. 2009). Based on the scarcity of killer whale sightings in the Beaufort Sea and the early winter timing of the proposed survey, it is unlikely that killer whales will be encountered.

(d) Harbor Porpoise (*Phocoena phocoena*)

The harbor porpoise is a small odontocete that inhabits shallow, coastal waters—temperate, subarctic, and arctic—in the Northern Hemisphere (Read 1999). Harbor porpoises occur mainly in shelf areas where they can dive to depths of at least 220 m and stay submerged for more than 5 min (Harwood and Wilson 2001) feeding on small schooling fish (Read 1999). Harbor porpoises typically occur in small groups of only a few individuals and tend to avoid vessels (Richardson et al. 1995a).

The subspecies *P. p. vomerina* ranges from the Chukchi Sea, Pribilof Islands, Unimak Island, and the southeastern shore of Bristol Bay south to San Luis Obispo, California. Point Barrow, Alaska, is the approximate northeastern extent of their regular range (Suydam and George 1992), though there are extralimital records east to the mouth of the Mackenzie River in the Northwest Territories, Canada and recent sightings in the Beaufort Sea in the vicinity of Prudhoe Bay during surveys in 2007 and 2008 (Christie et al. 2009). MMOs onboard industry vessels reported one harbor porpoise sighting in the Beaufort Sea in 2006 and no sightings were recorded in 2007 or 2008 (Savarese et al. 2009). Monnett and Treacy (2005) did not report any harbor porpoise sightings during aerial surveys in the Beaufort Sea from 2002 through 2004. Small numbers of harbor porpoises could occur in the general area of the proposed seismic survey.

Although separate harbor porpoise stocks for Alaska have not been identified, Alaskan harbor porpoises have been divided into three groups for management purposes. These groups include animals from southeast Alaska, Gulf of Alaska, and Bering Sea populations. Chukchi Sea harbor porpoises belong to the Bering Sea group which includes animals from Unimak Pass northward. Based on aerial surveys in 1999, the Bering Sea population was estimated at 48,215 animals, although this estimate is likely conservative as the surveyed area did not include known harbor porpoise range near the Pribilof Islands or waters north of Cape Newenhan (~55°N; Angliss and Allen 2009). Suydam and George (1992) suggested that harbor porpoises occasionally occur in the Chukchi Sea and reported nine records of harbor porpoise in the Barrow area in 1985–1991.

More recent vessel-based surveys in the Chukchi Sea found that the harbor porpoise was one of the most abundant cetaceans during summer and fall in 2006–2008 (Haley et al. 2009; Ireland et al. 2008). Although these recent sightings suggest that harbor porpoise numbers may be increasing in the relatively shallow waters of the Chukchi Sea, no recent information is available on the their status in deeper offshore waters. Harbor porpoises were not recorded during *Healy* cruises in the Arctic in 2005 or 2006 (Haley and Ireland 2006; Haley 2006). Harbor porpoise are not expected to be encountered during the proposed survey.

(2) Mysticetes

(a) Bowhead Whale (*Balaena mysticetus*)

Bowhead whales only occur at high latitudes in the northern hemisphere and have a disjunct circumpolar distribution (Reeves 1980). The bowhead is one of only three whale species that spend their entire lives in the Arctic. Bowhead whales are found in the western Arctic (Bering, Chukchi, and Beaufort seas), the Canadian Arctic and West Greenland (Baffin Bay, Davis Strait, and Hudson Bay), the Okhotsk Sea (eastern Russia), and the Northeast Atlantic from Spitzbergen westward to eastern Greenland. Four stocks are recognized for management purposes. The largest is the Western Arctic or Bering–Chukchi–Beaufort (BCB) stock, which includes whales that winter in the Bering Sea and migrate through the Bering Strait, Chukchi Sea and Alaskan Beaufort Sea to the Canadian Beaufort Sea, where they feed during the summer. These whales migrate west through the Alaskan Beaufort Sea in the fall as they return to wintering areas in the Bering Sea. Satellite tracking data indicate that some bowhead whales continue migrating west past Barrow and through the Chukchi Sea to Russian waters before turning south toward the Bering Sea (Quakenbush 2007). Some bowhead may reach ~75ºN latitude during the westward fall migration (Quakenbush 2009). Other researchers have also reported a westward movement of bowhead whales through the northern Chukchi Sea during fall migration (Moore et al. 1995; Mate et al. 2000).

The pre-exploitation population of bowhead whales in the Bering, Chukchi, and Beaufort seas is estimated to have been 10,400-23,000 whales. Commercial whaling activities may have reduced this population to perhaps 3,000 animals (Woodby and Botkin 1993). Up to the early 1990s, the population size was believed to be increasing at a rate of about 3.2% per year (Zeh et al. 1996) despite annual subsistence harvests of 14–74 bowheads from 1973 to 1997 (Suydam et al. 1995). A census in 2001 yielded an estimated annual population growth rate of 3.4% (95% CI 1.7–5%) from 1978 to 2001 and a population size (in 2001) of ~10,470 animals (George et al. 2004, recently revised to 10,545 by Zeh and Punt [2005]). A population estimate from photo identification data collected in 2004 was 11,800 (Koski et al. 2009) which further supports the estimated 3.4 percent population growth rate. Assuming a continuing annual population growth of 3.4%, the 2010 bowhead population may number around 14,247 animals. The large increases in population estimates that occurred from the late 1970s to the early 1990s were partly a result of actual population growth, but were also partly attributable to improved census techniques (Zeh et al. 1993). Although apparently recovering well, the BCB bowhead population is currently listed as endangered under the ESA and is classified as a strategic stock by NMFS and depleted under the MMPA (Angliss and Allen 2009).

The BCB stock of bowhead whales winters in the central and western Bering Sea and many of them summer in the Canadian Beaufort Sea and Amudsen Gulf (Moore and Reeves 1993). Spring migration through the Chukchi and the western Beaufort seas occurs through offshore ice leads, generally from mid-April to early June but with small numbers passing during March to mid-April and early- through mid-June (Braham et al. 1984; Moore and Reeves 1993; Koski et al. 2005).

Some bowheads arrive in coastal areas of the eastern Canadian Beaufort Sea and Amundsen Gulf in late May and June, but most may remain among the offshore pack ice of the Beaufort Sea until mid-summer. After feeding primarily in the Canadian Beaufort Sea and Amundsen Gulf, bowheads migrate westward from late August through mid- or late October.

Bowhead activity in the Beaufort Sea in fall has been well studied in recent years. Fall migration into the Alaskan Beaufort Sea is primarily during September and October. However, in recent years a small number of bowheads have been seen or heard offshore from the Prudhoe Bay region during the last week of August (Treacy 1993; LGL and Greeneridge 1996; Greene 1997; Greene et al. 1999; Blackwell et al. 2004, 2008; Greene et al. 2007). Satellite tracking of bowheads has also shown that some whales move to the Chukchi Sea prior to September (ADFG 2009). Consistent with this, Nuiqsut whalers have stated that the earliest arriving bowheads have apparently reached the Cross Island area earlier in recent years than formerly (T. Napageak, pers. comm.). In 2007 the MMS and the National Marine Mammal Laboratory (NMML) initiated the Bowhead Whale Feeding Ecology Study (BOWFEST) focusing on late summer oceanography and prey densities relative to bowhead distribution (Rugh et al. 2009).

The Minerals Management Service (MMS) has conducted or funded late-summer/autumn aerial surveys for bowhead whales in the Alaskan Beaufort Sea since 1979 (e.g., Ljungblad et al. 1986, 1987; Moore et al. 1989; Treacy 1988–1998, 2000, 2002a,b; Monnett and Treacy 2005; Treacy et al. 2006). Bowheads tend to migrate west in deeper water (farther offshore) during years with higher-than-average ice coverage than in years with less ice (Moore 2000; Treacy et al. 2006). The migration corridor ranged from ~30 km offshore during light ice years to ~80 km offshore during heavy ice years (Treacy et al. 2006). In addition, the sighting rate tends to be lower in heavy ice years (Treacy 1997:67). During fall migration, most bowheads migrate west in water ranging from 15 to 200 m deep (Miller et al. 2002 *in* Richardson and Thomson 2002). Some individuals enter shallower water, particularly in light ice years, but very few whales are ever seen shoreward of the barrier islands in the Alaskan Beaufort Sea. Survey coverage far offshore in deep water is usually limited, and offshore movements may have been underestimated. However, the main migration corridor is over the continental shelf.

In autumn, westward-migrating bowhead whales typically reach the Kaktovik and Cross Island areas in early September, when the subsistence hunts for bowheads typically begin in those areas (Kaleak

1996; Long 1996; Galginaitis and Koski 2002; Galginaitis and Funk 2004, 2005; Koski et al. 2005). In recent years the hunts at those two locations have usually ended by mid- to late September.

Westbound bowheads typically reach the Barrow area in mid-September, and are in that area until late October (e.g., Brower 1996). Autumn bowhead whaling near Barrow normally begins in mid-September to early October, but may begin as early as August if whales are observed and ice conditions are favorable (USDI/BLM 2005). Whaling near Barrow can continue into October, depending on the quota and conditions.

Over the years, local residents have reported small numbers of bowhead whales feeding off Barrow or in the pack ice off Barrow during the summer. Bowhead whales that are thought to be part of the Western Arctic stock may also occur in small numbers in the Bering and Chukchi seas during the summer (Moore 1992; Rugh et al. 2003). Thomas et al. (2009) reported bowhead sightings during summer aerial surveys in nearshore areas of the Chukchi Sea from 2006–2008. All sightings were recorded in the northern portion of the study area north of 70°N latitude. Peak monthly bowhead sighting rates, however, were highest in October and November and lowest in July-September. A few bowhead whales were also recorded during vessel-based surveys in summer 2008 in the Chukchi Sea (Funk et al. 2009). Observers from the NMML reported 19 summer bowhead sightings in the Chukchi Sea during aerial surveys from 26 June through 26 July 2009 suggesting that some bowheads may summer in the Chukchi Sea (unpublished data available at http://www.afsc.noaa.gov/NMML/cetacean/bwasp/flights_COMIDA.php). Only one bowhead sighting was reported during similar surveys in 2008, and was recorded later in the year (22 August). Sekiguchi et al. (2008) reported one sighting of an aggregation of ~30 bowheads during vessel-based operations about 130 km north of Cape Lisburne on 9 August 2007. Bowhead whales were not reported by vessel-based observers on the *Healy* during arctic cruises in 2005 and 2006 (Haley and Ireland 2006; Haley 2006).

It is possible that bowhead whales could be encountered in October as the whales migrate westward/southward into the Chukchi Sea, however, most bowheads will have migrated outside of the proposed survey area before the survey is underway. To minimize the chance of encounters with migrating bowhead whales the proposed survey will begin in offshore waters deeper than 1000 m, move into continental shelf waters at the eastern end of the study area in mid-October, and then progress westward. Under this survey design it is expected that encounters with bowhead whales will be much lower than a survey planned during the open water season.

(b) Gray Whale (*Eschrichtius robustus*)

Gray whales originally inhabited both the North Atlantic and North Pacific oceans. The Atlantic populations are believed to have become extinct by the early 1700s. There are two populations in the North Pacific. A relic population which survives in the Western Pacific summers near Sakhalin Island far from the proposed survey area. The larger eastern Pacific or California gray whale population recovered significantly from commercial whaling during its protection under the ESA until 1994 and numbered about 29,758 ±3122 in 1997 (Rugh et al. 2005). However, abundance estimates since 1997 indicate a consistent decline followed by the population stabilizing or gradually recovering. Rugh et al. (2005) estimated the population to be 18,178 ±1780 in winter 2001–2002. The population estimate increased during winter 2006-2007 to 20,110 ±1766 (Rugh et al. 2008). The eastern Pacific stock is not considered by NMFS to be endangered or to be a strategic stock.

Eastern Pacific gray whales calve in the protected waters along the west coast of Baja California and the east coast of the Gulf of California from January to April (Swartz and Jones 1981; Jones and Swartz 1984). At the end of the calving season, most of these gray whales migrate about 8,000 km, generally along the west coast of North America, to the main summer feeding grounds in the northern Bering and Chukchi seas (Tomilin 1957; Rice and Wolman 1971; Braham 1984; Nerini 1984; Moore et al. 2003; Bluhm et al. 2007). Most gray whales begin southward migration in November with breeding and conception occurring in early December (Rice and Wolman 1971).

Most summering gray whales have historically congregated in the northern Bering Sea, particularly off St. Lawrence Island in the Chirikov Basin (Moore et al. 2000a), and in the southern Chukchi Sea. More recently, Moore et al. (2003) suggested that gray whale use of Chirikov Basin has decreased, likely as a result of the combined effects of changing currents resulting in altered secondary productivity dominated by lower quality food. Coyle et al (2007) noted that ampeliscid amphipod production in the Chirikov Basin had declined by 50% from the 1980s to 2002–2003 and that as little as 3–6% of the current gray whale population could consume 10–20% of the ampeliscid amphipod annual production. These data support the hypotheses that changes in gray whale distribution may be caused by changes in food production and that gray whales may be approaching or have surpassed the carrying capacity of their summer feeding areas. Bluhm et al. (2007) noted high gray whale densities along ocean fronts and suggested that ocean fronts may play an important role in influencing prey densities in eastern North Pacific gray whale foraging areas. The northeastern-most of the recurring feeding areas is in the northeastern Chukchi Sea southwest of Barrow (Clarke et al. 1989).

Gray whales occur regularly near Point Barrow, but historically only a small number of gray whales have been sighted in the Beaufort Sea east of Point Barrow. Hunters at Cross Island (near Prudhoe Bay) took a single gray whale in 1933 (Maher 1960). Only one gray whale was sighted in the central Alaskan Beaufort Sea during the extensive aerial survey programs funded by MMS and industry from 1979 to 1997. However, during September 1998, small numbers of gray whales were sighted on several occasions in the central Alaskan Beaufort Sea (Miller et al. 1999; Treacy 2000). More recently a single sighting of a gray whale was made on 1 August 2001 near the Northstar production island (Williams and Coltrane 2002). Several gray whale sightings were reported during both vessel-based and aerial surveys in the Beaufort Sea in 2006-2008 (Christie et al. 2009; Savarese et al. 2009). Several single gray whales have been seen farther east in the Canadian Beaufort Sea (Rugh and Fraker 1981), indicating that small numbers must travel through the Alaskan Beaufort during some summers. In recent years, ice conditions have become lighter near Barrow, and gray whales may have become more common there and perhaps in the Beaufort Sea. In the springs of 2003 and 2004, a few tens of gray whales were seen near Barrow by early-to-mid June (LGL Ltd and NSB-DWM, unpubl. data). However, no gray whales were sighted during cruises north of Barrow in 2002, 2005 or 2006 (Harwood et al. 2005; Haley and Ireland 2006; Haley 2006).

Few, if any, gray whales are expected to be encountered during the proposed survey. Gray whales are not commonly observed in the Beaufort Sea, and it is unlikely that gray whales will be encountered in the northern Chukchi Sea during the early winter timing of the survey.

(c) Minke Whale (*Balaenoptera acutorostrata*)

Minke whales have a cosmopolitan distribution at ice-free latitudes (Stewart and Leatherwood 1985), and also occur in some marginal ice areas. Angliss and Allen (2009) recognize two minke whale stocks in U.S. waters: (1) the Alaska stock, and (2) the California/Oregon/Washington stock. There is no abundance estimate for the Alaska stock. Provisional estimates of minke whale abundance based on surveys in 1999 and 2000 are 810 and 1,003 whales in the central-eastern and south-eastern Bering Sea, respectively (Moore et al. 2002). These estimates have not been corrected for animals that may have been submerged or otherwise missed during the surveys, and only a portion of the range of the Alaskan stock was surveyed.

Minke whales range into the Chukchi Sea and a few sightings have been reported in the Beaufort Sea in recent years (Funk et al. 2009). The level of Minke whale use of the Chukchi Sea is unknown. Leatherwood et al. (1982, *in* Angliss and Allen 2009) indicated that minke whales are not considered abundant in any part of their range, but that some individuals venture north of the Bering Strait in summer. Reiser et al. (2008) reported eight and five Minke whale sightings in 2006 and 2007, respectively, during vessel-based surveys in the Chukchi Sea, and Haley et al. (2009) reported 26 Minke whale sightings during similar vessel-based surveys in the Chukchi Sea in 2008. Savarese et al. (2009) reported two Minke whale sightings in the Beaufort Sea during vessel-based operations in 2006–2008. No Minke whale sighting were reported during Arctic cruises by the *Healy* in 2005 or 2006 (Haley and Ireland 2006; Haley 2006). All previous Minke whale sightings occurred earlier in the year. Minke whale sightings are unlikely to occur in the survey area during October–December.

(d) Fin Whale (*Balaenoptera physalus*)

Fin whales are widely distributed in all the world's oceans (Gambell 1985), but typically occur in temperate and polar latitudes and less frequently in the tropics (Reeves et al. 2002). Fin whales feed in northern latitudes during the summer where their prey includes plankton as well as schooling pelagic fish, such as herring, sandlance, and capelin (Jonsgård 1966a,b; Reeves et al. 2002). The North Pacific population summers from the Chukchi Sea in small numbers to California (Gambell 1985), but does not range into the Alaskan Beaufort Sea or waters of the northern Chukchi Sea. Reliable estimates of fin whale abundance in the Northeast Pacific are not available (Angliss and Allen 2009). Provisional estimates of fin whale abundance in the central-eastern and south-eastern Bering Sea are 3,368 and 683, respectively (Moore et al. 2002). Zerbini et al. (2006) reported numerous fin whale sightings from Kodiak Island to the central Aleutian Islands.

Fin whales were not recorded during vessel-based or aerial surveys in the Beaufort Sea in 2006-2008 (Savarese et al. 2009; Christie et al. 2009), and were not reported during arctic cruises from the *Healy* in 2005 or 2006 (Haley and Ireland 2006; Haley 2006). Fin whale would be unlikely to occur in the proposed geophysical survey area. Fin whale is listed as endangered under the ESA and by IUCN, is classified as a strategic stock by NMFS, and is a CITES Appendix I species.

(e) Humpback Whale (*Megaptera novaeangliae*)

Humpback whales are distributed in major oceans worldwide and their range in the North Pacific extends through the Bering Sea into the southern Chukchi Sea (Angliss and Allen 2009). In general, humpback whales spend winter in tropical and sub-tropical waters where breeding and calving occur, and migrate to higher latitudes for feeding during the summer.

Humpback whales were hunted extensively during the 20th century and worldwide populations may have been reduced to ~10% of their original numbers. The International Whaling Commission banned commercial hunting of humpback whales in the Pacific Ocean in 1965 and humpbacks were listed as endangered under the ESA and depleted under the MMPA in 1973. Most humpback whale populations appear to be recovering well.

Humpback whale sightings in the Bering Sea have been recorded southwest of St. Lawrence Island, the southeastern Bering Sea, and north of the central Aleutian Islands (Moore et al. 2002; Angliss and Allen 2009). Recently there have been sightings of humpback whales in the Chukchi Sea and a single sighting in the Beaufort Sea (Green et al. 2007). Haley et al (2009) reported four humpback whales during vessel-based surveys in the Chukchi Sea in 2007 and two sightings in 2008. NMML observers recorded a humpback whale during aerial surveys in the Chukchi Sea in 2009. Green et al. (2007) reported and photographed a humpback whale cow/calf pair east of Barrow near Smith Bay in 2007. No humpback whales were reported during cruises aboard the Healy in 2005 or 2006 (Haley and Ireland 2006; Haley 2006). Whether the recent humpback whale sightings in the Chukchi and Beaufort seas are related to climate changes in the Arctic in recent years is unknown. Humpback whales would be unlikely to occur in the proposed survey area due to the low numbers that occur in the area and the early winter timing of the survey when humpback whales are typically migrating south to their breeding/calving grounds.

(3) Pinnipeds

(a) Pacific Walrus (*Odobenus rosmarus divergens*)

Walruses occur in moving pack ice over shallow waters of the circumpolar Arctic coast (King 1983). There are two recognized subspecies of walrus: the Pacific and Atlantic walrus (*O. r. divergens* and *O. r. rosmarus*, respectively.). Only the *divergens* subspecies could potentially occur within the proposed geophysical survey area.

Estimates of the pre-exploitation population of the Pacific walrus range from 200,000 to 400,000 animals (Angliss and Allen 2009). Over the past 150 years, the population has been depleted by over-harvesting and then periodically allowed to recover (Fay et al. 1989). No current population estimate is available. The USFWS and the USGS are currently investigating new techniques, including remote sensing, for producing a more precise abundance estimate of the Pacific walrus population (Burn et al. 2006; Udevitz et al. 2008).

Pacific walruses range from the Bering Sea to the Chukchi Sea, occasionally moving into the East Siberian and Beaufort seas. Walruses are migratory, moving south with the advancing ice in autumn and north as the ice recedes in spring (Fay 1981). In the summer, most of the population of Pacific walrus moves to the Chukchi Sea, but several thousand aggregate in the Gulf of Anadyr and in Bristol Bay (Angliss and Allen 2009). Limited numbers of walruses inhabit the Beaufort Sea during the open water season, and they are considered extralimital east of Point Barrow (Sease and Chapman 1988). The northeast Chukchi Sea west of Barrow is the northeastern extent of the main summer range of the Pacific walrus, and only a few are seen farther east in the Beaufort Sea (e.g., Harwood et al. 2005; Savarese et al. 2009). The estimated average annual walrus mortality due to subsistence harvest in Russia and the U.S. was 5789, which included animals wounded but not retrieved (Angliss and Allen 2009).

Walruses are most commonly found near the southern margins of the pack ice as opposed to deep in the pack where few open leads (polynyas) exist to afford access to the sea for foraging (Estes and Gilbert 1978; Gilbert 1989; Fay 1982). Walruses are not typically found in areas of >80% ice cover (Fay 1982). Ice serves as an important mobile platform providing walruses with a place to rest and nurse their young which is safe from predators and near feeding grounds.

This close relationship to the ice largely determines walrus distribution and the timing of their migrations. As the pack ice breaks up in the Bering Sea and recedes northward in May-June, a majority of subadults, females and calves migrate with it, either by swimming or resting on drifting ice sheets. Many males will choose to stay in the Bering Sea for the entire year, with concentrations near Saint Lawrence Island and further south in Bristol Bay. Two northward migration pathways are apparent, either toward the eastern Chukchi Sea near Barrow or northwestward toward Wrangel Island. By late June to early July, concentrations of walruses migrating northeastward spread along the Alaska coast concentrated within 200 km of the shore from Saint Lawrence Island to southwest of Barrow. In August, largely dependent on the retreat of the pack ice, walruses are found further offshore with principal concentrations northwest of Barrow. By October, a reverse migration occurs from the Chukchi Sea, with animals swimming ahead of the developing pack ice (Fay 1982).

Pacific walruses feed primarily on benthic invertebrates, occasionally fish and cephalopods, and more rarely, some adult males may prey on other pinnipeds (reviewed *in* Riedman 1990). Walruses typically feed in depths of 10–80 m (Vibe 1950; Fay 1982; Reeves et al. 2002). In a recent study in Bristol Bay, 98% of satellite locations of tagged walruses were in water depths of 60 m or less (Chadwick and Hills 2005). Though the deepest dive recorded for a walrus was 133 m, they are more likely to be found in depths of 80 m or less in coastal or continental shelf habitats, where they feed on clams and other marine mollusks (Fay 1982; Fay and Burns 1988; Reeves et al. 2002).

Recently global climate changes have apparently resulted in retreat of the pack ice beyond the shallow habitats of the Chukchi Sea into deeper waters of the Arctic Ocean during summer months. Water depths in the Arctic Ocean are too great to permit walrus feeding and many thousands of walruses hauled out to rest at terrestrial sites along the eastern Chukchi Sea coast in 2007 (Thomas et al. 2009). A similar situation occurred when the pack ice retreated and walruses were forced to use terrestrial haulouts. In 2009 over 100 walruses, primarily smaller, young animals, died at haulouts apparently as a result of injuries sustained by stampeding adults. Similar mortality incidents were not reported in Alaska during 2007. Belikov et al. (1996) also reported similar use of terrestrial haulouts by walrus in during years of excessive ice retreat in Russia. The Center for Biological Diversity petitioned the Secretary of Interior to list Pacific walrus as a threatened or endangered species under the ESA primarily as a result of potential impacts from global climate change and associated retreat of the pack ice (CBD 2008).

While walruses have certainly been encountered and are present in the Beaufort Sea, there were only five sightings of walruses between 146° and 150° W during annual aerial surveys conducted from 1979 to 1995 (LGL and Greeneridge 1996). In addition, from 1993-2004, nine walrus sightings have been reported during industry monitoring efforts in the Beaufort Sea (Kalxdorff and Bridges 2003; USFWS unpub. data). Walruses could be encountered during transit periods in the Chukchi Sea, but based on the limited number of reported walrus sightings in the Beaufort Sea, and the proposed timing of the survey, it is unlikely walrus will be encountered in the study area. However, an occasional sighting may occur, similar to the one on 2 October 2007, when two walruses were observed on the Endicott beach (Sanzone et al. 2008).

(b) Bearded Seal (*Erignathus barbatus*)

Bearded seals are associated with sea ice and have a circumpolar distribution (Burns 1981b). During the open-water period, bearded seals occur mainly in relatively shallow areas, because they are predominantly benthic feeders (Burns 1981b). They prefer areas of water no deeper than 200 m (Harwood et al. 2005). No reliable estimate of bearded seal abundance is available for the Chukchi and Beaufort seas (Angliss and Allen 2009). The Alaska stock of bearded seals is not classified by NMFS as endangered or a strategic stock. However, a decision to list the species under the ESA due to the potential impact to seal habitats resulting from current warming trends is still under consideration by the NMFS.

The bearded seal is the largest of the northern phocids. Bearded seals have occasionally been reported to maintain breathing holes in sea ice; however, in winter they are found primarily in areas with persistent leads or cracks in broken areas within the pack ice, particularly if the water depth is <200 m. Bearded seals apparently also feed on ice-associated organisms when they are present, and this allows a few bearded seals to live in areas considerably more than 200 m deep.

Seasonal movements of bearded seals are directly related to the advance and retreat of sea ice and to water depth (Kelly 1988). During winter, most bearded seals in Alaskan waters are found in the Bering Sea. In the Chukchi and Beaufort seas, favorable conditions are more limited, and consequently, bearded seals are less abundant there during winter. From mid-April to June as the ice recedes, some bearded seals that overwintered in the Bering Sea migrate northward through the Bering Strait. During the summer they are found near the widely fragmented margin of multi-year ice covering the continental shelf of the Chukchi Sea and in nearshore areas of the central and western Beaufort Sea. In the Beaufort Sea, bearded seals rarely use coastal haulouts.

In some areas, bearded seals are associated with the ice year-round; however, they usually move shoreward into open water areas when the pack ice retreats to areas with water depths greater than 200 m (Cameron et al. 2009). In the Beaufort Sea, suitable habitat is limited because the continental shelf is narrow and the pack ice edge frequently occurs seaward of the shelf and over water too deep for benthic feeding. The preferred habitat in the western and central Beaufort Sea during the open-water period is the continental shelf seaward of the scour zone, although a recent tagging study showed occasional movements of adult bearded seals seaward of the continental shelf (Cameron et al. 2009). WesternGeco conducted marine mammal monitoring during its open-water seismic program in the Alaskan Beaufort Sea from 1996 to 2001. Operations were conducted in nearshore waters, and of a total 454 seals that were identified to species while no airguns were operating, 4.4% were bearded seals, 94.1% were ringed seals and 1.5% were spotted seals (Moulton and Lawson 2002). Haley and Ireland (2006) and Haley (2006) also reported much lower percentages of bearded compared to ringed seals during *Healy* cruises in the Arctic.

In Alaskan waters, bearded seals occur over the continental shelves of the Bering, Chukchi, and Beaufort seas (Burns 1981b). The Alaska stock of bearded seals may consist of about 300,000–450,000 individuals (MMS 1996; Angliss and Allen 2009). In the Beaufort Sea Savarese et al. (2009) reported bearded seal densities up to 0.028 and 0.035 seals/km^2 in the summer and fall, respectively during vessel-based surveys in 2006–2008. Haley and Ireland (2006) reported only 7 bearded seal sightings during an arctic cruise from the *Healy* in 2005, and 14 bearded seal sightings were reported during the 2006 *Healy* cruise (Haley 2006).

It is unlikely that large numbers of bearded seals would be encountered during the proposed survey because they would typically migrate south into the Chukchi and Bering seas in early winter with the advancing pack ice. It is possible that bearded seals would be encountered during the transit south following operations.

(c) Spotted Seal (*Phoca largha*)

Spotted seals, also known as largha seals, occur in the Beaufort, Chukchi, Bering and Okhotsk seas, and south to the northern Yellow Sea and western Sea of Japan (Shaughnessy and Fay 1977). They migrate south from the Chukchi Sea and through the Bering Sea in October (Lowry et al. 1998). Spotted seals overwinter in the Bering Sea and inhabit the southern margin of the ice during spring (Shaughnessy and Fay 1977).

An early estimate of the size of the world population of spotted seals was 370,000–420,000, and the size of the Bering Sea population, including animals in Russian waters, was estimated to be 200,000–250,000 animals (Bigg 1981). The current total number of spotted seals in Alaskan waters is not known (Angliss and Allen 2009), but the estimate is most likely between several thousand and several tens of thousands (Rugh et al. 1997). The Alaska stock of spotted seals is not classified as endangered or as a strategic stock by NMFS (Hill and DeMaster 1998). In response to a petition to list spotted seals under the Endangered Species Act (CBD 2008), NMFS concluded that only the southern distinct population segment (DPS) which occurs in Japan, outside of U.S. waters, merited listing.

During the summer spotted seals are found in Alaska from Bristol Bay through western Alaska to the Chukchi and Beaufort seas. The ADF&G placed satellite transmitters on 4 spotted seals and estimated that the proportion of seals hauled out was 6.8%. Based on an actual minimum count of 4,145 hauled out seals, Angliss and Allen (2009) estimated the Alaskan population at 59,214 animals. The Alaska stock of spotted seals is not classified as endangered, threatened, or as a strategic stock by NMFS (Angliss and Allen 2009), although the southern distinct population segment (DPS) of spotted seals was recently listed as a threatened species, it occurs entirely outside of US waters.

During spring when pupping, breeding, and molting occur, spotted seals are found along the southern edge of the sea ice in the Okhotsk and Bering seas (Quakenbush 1988; Rugh et al. 1997). In late April and early May, adult spotted seals are often seen on the ice in female-pup or male-female pairs, or in male-female-pup triads. Subadults may be seen in larger groups of up to two hundred animals. During the summer, spotted seals are found primarily in the Bering and Chukchi seas, but some range into the Beaufort Sea (Rugh et al. 1997; Lowry et al. 1998) from July until September. At this time of year, spotted seals haul out on land part of the time, but also spend extended periods at sea. Spotted seals are commonly seen in bays, lagoons and estuaries, but also range far offshore as far north as 69–72º N. As the ice cover thickens with the onset of winter, spotted seals leave the northern portions of their range and move into the Bering Sea (Lowry et al. 1998).

Relatively low numbers of spotted seals are present in the Beaufort Sea. A small number of spotted seal haulouts are (or were) located in the central Beaufort Sea in the deltas of the Colville River and previously the Sagavanirktok River. Historically, these sites supported as many as 400–600 spotted seals, but in the 1990s <20 were seen at any one site (Johnson et al. 1999). A total of 12 spotted seals were positively identified near the source vessel during open-water seismic programs in the central Alaskan Beaufort Sea during the 6 years from 1996 to 2001 (Moulton and Lawson 2002, p. 317). Numbers seen per year ranged from zero (in 1998 and 2000) to four (in 1999). More recently Green et al. (2007) reported 46 spotted seal sightings during barge operations between West Dock and Cape Simpson. Most sightings occurred from western Harrison Bay to Cape Simpson with only one sighting offshore of the Colville River delta. No spotted seals were recorded from the *Healy* during arctic cruises in 2005 or 2006 (Haley and Ireland 2006; Haley 2006).

Spotted seals leave the northern portions of their range with the onset of winter and move into the Bering Sea (Lowry et al. 1998); therefore it is unlikely that spotted seals would be encountered in the proposed study area in October–December. It is possible that spotted seals would be encountered during the transit south following operations.

(d) Ringed Seal (*Phoca hispida*)

Ringed seals have a circumpolar distribution and occur in all seas of the Arctic Ocean (King 1983). During late fall and winter, ringed seals occupy landfast ice and offshore pack ice of the Bering, Chukchi and Beaufort seas (Angliss and Allen 2009). In winter and spring, the highest densities of ringed seals are found on stable shorefast ice. However, in some areas where there is limited fast ice but wide expanses of pack ice, including the Beaufort Sea, Chukchi Sea and Baffin Bay, total numbers of ringed seals on pack ice may exceed those on shorefast ice (Burns 1970; Stirling et al. 1982; Finley et al. 1983). Shorefast ice begins to form in October–November, and persists until May–July, depending on the location. At its maximum extent the shorefast ice extends seaward to about the 20 m isobath, which may be 40 km or more offshore (Stringer et al. 1980).

Ringed seals make breathing holes in the newly formed ice and maintain the breathing holes as the ice thickens (Smith and Stirling 1975; Smith and Hammill 1981). In areas with ice hummocks and pressure ridges, snow accumulates over seal breathing holes, and the seals hollow out subnivean lairs in this snow (Smith and Stirling 1975). Pregnant females give birth in lairs from mid-March through April, nurse their pups in the lairs for 5–8 weeks, and mate in late April and May (Smith 1973; Hammill et al. 1991; Lydersen and Hammill 1993).

Ringed seals are year-round residents in the Beaufort Sea and ringed seal is the most frequently encountered seal species in the area. No estimate for the size of the Alaska ringed seal stock is currently available (Angliss and Allen 2009). Past ringed seal population estimates in the Bering-Chukchi-Beaufort area ranged from 1–1.5 million (Frost 1985) to 3.3–3.6 million (Frost et al. 1988). Frost and Lowry (1981) estimated 80,000 ringed seals in the Beaufort Sea during summer and 40,000 during winter. More recent estimates based on extrapolation from aerial surveys and on predation estimates for polar bears (Amstrup 1995) suggest an Alaskan Beaufort Sea population at ~326,500 animals. The Alaska stock of ringed seals is not endangered, and is not classified as a strategic stock by NMFS. However, a decision to list the species under the ESA, due to the potential impact to seal habitats resulting from current warming trends, is still under consideration by the NMFS.

Frost et al. (2004) report ringed seal densities during aerial surveys in the central Alaskan Beaufort Sea during late May and early June 1996–1999 were highest in water depths between 5 and 35 m. Densities were also highest in relatively flat ice and near the fast ice edge, declining both shoreward and seaward of that edge (Frost et al 2004). It is unclear what makes the fast ice edge so attractive to ringed seals and results in higher densities in that region. Seal distribution and density in late May and early June, prior to breakup, are thought to reflect distribution patterns established earlier in the year. Higher abundance could indicate greater prey availability during fall and winter, when seals are actively feeding and when breathing holes are established (Frost et al. 2004). During late fall and winter, a seasonal shift in the ringed seal diet from hyperiid amphipods to Arctic cod occurs in the central Beaufort Sea (Lowry et al. 1980; Bluhm and Gradinger 2008). Arctic cod occur in nearshore areas and spawn during November – February (Craig et al. 1982), and this ephemeral prey resource may attract ringed seals.

The availability of sea ice habitat used by ringed seals varies on short (daily and weekly) as well as long (annual and decadal) time scales. Weather at the time of freeze-up and throughout the winter affects the ice roughness and snow cover, which in turn determine the suitability of ice as ringed seal habitat. Even within the same season, snow and ice conditions may change drastically within just a few days. This is particularly true along the coastlines of Alaska, where fast ice occurs as an unprotected, linear band that abuts the pack ice and may be heavily impacted by storms and ocean currents. This variability makes between-year comparisons along the Alaska coast very difficult (Frost et al. 1988).

Savarese et al. (2009) reported that ringed seal was the most abundant seal species in the Beaufort Sea during vessel-based surveys in 2006–2008 with densities up to 0.068 and 0.096 seals/km^2 in the summer and fall, respectively. Haley et al. (2009) also reported that ringed seal was the most abundant seal species during similar vessel-based surveys in the Chukchi Sea during the same period with densities up to 0.054 and 0.171 seals/km^2 in summer and fall, respectively. Many unidentified seals during these surveys may have also been ringed seals and actual densities may have been higher.

Moulton et al. (2002) reported ringed seal densities (uncorrected) ranging from 0.43 to 0.63 seal per km^2 in water 3–35 m in depth during aerial surveys during late spring in the central Alaskan Beaufort Sea. In a similar study that covered a broader area, Frost et al. (2004) observed (uncorrected) densities ranging from 0.92 to 1.33 seals per km^2. Densities were higher in nearshore than offshore locations, however these aerial surveys did not extend beyond 40 km offshore. Ringed seals are likely to be encountered during the proposed geophysical survey.

(e) Ribbon Seal (*Histriophoca fasciata*)

Ribbon seals are found along the pack-ice margin in the southern Bering Sea during late winter and early spring and they move north as the pack ice recedes during late spring to early summer (Burns 1970; Burns et al. 1981a). Little is known about their summer and fall distribution, but Kelly (1988) suggested that they move into the southern Chukchi Sea based on a review of sightings during the summer. During a recent satellite telemetry program sponsored by the NMML, a number of ribbon seals tagged in the Bering Sea in May had moved to the Chukchi Sea by July (NMML 2009). However, ribbon seals appeared to be relatively rare in the northern Chukchi Sea during recent vessel-based surveys in summer and fall of 2006–2008 with only three sightings among 1778 sightings of seals identified to species (Haley et al. 2009). Ribbon seals do not normally occur in the Beaufort Sea, however three recent ribbon seal sightings were reported during vessel-based activities in the Beaufort Sea in 2007–2008 (Savarese et al. 2009). In response to a petition to list ribbon seal under the Endangered Species Act (CBD 2007), a recent announcement by NMFS indicated that listing of ribbon seal was not warranted at this time (NMFS 2008). Ribbon seals would be unlikely to occur in the proposed survey area in October–December during the period of the proposed survey.

(4) Carnivora

(a) Polar Bear (*Ursus maritimus*)

Polar bears have a circumpolar distribution throughout the northern hemisphere (Amstrup et al. 1986) and occur in relatively low densities throughout most ice-covered areas (DeMaster and Stirling 1981). Polar bears are divided into 19 relatively distinct populations or management units although there may be overlap of some individuals among populations (Aars et al. 2006; USFWS 2008). Polar bears are common in the Chukchi and Beaufort Seas north of Alaska throughout the year, including the late fall-early winter period (Garner et al. 1990, Amstrup and Gardner 1994, Amstrup et al. 2000, Moulton and Williams 2003, Harwood et al. 2005). They also occur throughout the East Siberian, Laptev, and Kara Seas of Russia and the Barent's Sea of northern Europe. They are found in the northern part of the Greenland Sea, and are common in Baffin Bay, which separates Canada and Greenland, as well as through most of the Canadian Arctic Archipelago.

Current world population estimates for the polar bear range from ~20,000 to 30,000 bears (Derocher et al. 1998; Aars et al. 2006). Three polar bear populations are of concern for the proposed geophysical survey. The Southern Beaufort Sea population with ~1500 bears ranges from the Baillie Islands, Canada, in the east to near Point Lay, Alaska, in the west. The Chukchi Sea population with ~2,000 bears includes most of the Chukchi Sea and the northern Bering Sea. The Northern Beaufort Sea population with ~1,200 bears is located in Canadian waters primarily north of the Southern Beaufort Sea and extending into Admunsen Gulf. USFWS (2008) designated the Northern Beaufort Sea population as stable, the Southern Beaufort Sea population as declining, and the Chukchi Sea population as data deficient. Data from tracking studies indicate wide-ranging movements of individual bears and overlap among polar bear populations (Garner et al. 1990; Amstrup 1995; Durner and Amstrup 1995).

Polar bear populations are protected under the Marine Mammal Protection Act of 1973, as well as by the International Agreement on the Conservation of Polar Bears, ratified in 1976. Countries participating in the latter treaty include Canada, Denmark, Norway, Russia (former USSR), and the USA. Article II of the agreement states, “Each contracting party…shall manage polar bear populations in accordance with sound conservation practices based on the best scientific data.” USFWS (2008) listed polar bear as a threatened species under the U.S. ESA based on the expected continuation of declines in sea ice which is their principal habitat. The USFWS has also recently proposed to designate critical habitat for polar bear populations in the U.S. under the ESA. The critical habitat proposal identifies habitat in three separate areas: barrier island habitat, sea ice habitat and terrestrial denning habitat. The total area proposed for designation would cover approximately 519, 403 km^2 (200, 541 mi^2) and is found entirely within the lands and waters in the United States. Barrier island habitat includes coastal barrier islands and spits along Alaska's coasts. Sea ice habitat is located over the continental shelf, and includes water 300 m and less in depth. Terrestrial denning habitat includes lands within 32 km of the northern coast of Alaska between the Canadian border and the Kavik River and within 8 km between the Kavik River and Barrow.

Polar bears usually forage in areas where there are high concentrations of ringed seals, which is their primary prey, and bearded seals (Larsen 1985; Stirling and McEwan 1975). This includes areas of land-fast ice, as well as moving pack ice. Polar bears are opportunistic feeders and feed on a variety of foods and carcasses including not only seals but also beluga whales, arctic cod, geese and their eggs, walruses, bowhead whales, and reindeer (Smith 1985; Jefferson et al. 1993; Smith and Hill 1996; Derocher et al. 2000).

Females give birth to 1 to 3 cubs at an average interval of every 3.6 years (Jefferson et al. 1993; Lentfer et al. 1980). Cubs remain with their mothers for 1.4 to 3.4 years (Derocher et al. 1993; Ramsay and Stirling 1988). Mating occurs from April to June followed by a delayed implantation during September to December. Females give birth usually the following December or January (Harington 1968; Jefferson et al. 1993). In general, females 6 years of age or older successfully wean more cubs than younger bears; however, females as young as 4 years old can produce offspring (Ramsay and Stirling 1988). An examination of reproductive rates of polar bears indicated that 5% of four-year-old females had cubs, whereas 50% of five year-old females had cubs (Ramsay and Stirling 1988). Females that were over 20 years had a very high rate of cub loss or did not successfully reproduce. The maximum reproductive age reported for Alaskan polar bears is 18 years (Amstrup and DeMaster 1988).

Polar bears typically range as far north as 88°N (Ray 1971; Durner and Amstrup 1995) where the population thins dramatically. However, polar bears have been observed across the Arctic, including close to the North Pole (van Meurs and Splettstoesser 2003). Polar bears typically move north from May through August and remain with the pack ice edge during fall. However, recent aerial surveys, as well as, observations from Native villagers suggest that Alaskan polar bear populations, including the Southern Beaufort Sea and Chukchi Sea, have been increasing their use of land during the fall open-water period in the Alaskan Southern Beaufort Sea (Monnett et al. 2005; Monnett and Gleason 2006).

Polar bears that come on land in most areas typically consume minimal, if any, food and therefore, spend the duration fasting while they await the re-formation of ice needed to access and hunt seals (Derocher et al. 1993; Atkinson and Ramsay 1995). Some of the bears that come ashore on the North Slope of Alaska spend time foraging on subsistence-harvested bowhead whale carcasses. Three communities, Barrow, Nuiqsut, and Kaktovik, consistently harvest bowhead whales each fall, and as many as 65 polar bears have been observed feeding at a single bowhead whale carcass (Miller et al. 2006). Bowhead whale carcasses have been available to polar bears at these locations since the early 1970s (Koski et al. 2005).

Aerial surveys along the Southern Beaufort Sea coastline between Barrow and the Canadian border during September and October 2005-2006 concluded that polar bear densities along the mainland coast and on barrier islands during the fall open-water period were related to the distance between shore and the pack ice edge and the density of ringed seals over the continental shelf (Schliebe et al. 2008). Therefore, if the extent of summer pack-ice continues to decline as predicted by some climate models (Zhang and Walsh 2006; Serreze et al. 2007; Stroeve et al. 2007), polar bears may be more likely to come ashore during this time to gain access to ringed seals over the continental shelf on recently frozen land-fast ice in the fall, rather than remain on pack-ice where they may wait a longer period for ice to extend over the shelf (Schliebe et al. 2008).

Regardless of whether the polar bears are moving from their summering areas on the pack ice or from land, the majority of polar bears will be present on the annual sea ice that has formed over the shallow nearshore waters (300 m or less) during the proposed time of the seismic survey, October-December (Amstrup et al. 2000; Schliebe et al. 2008). This is presumably because ringed seals are available and accessible in the shallower more productive waters over the continental shelf during this time of year (USFWS 1995; Stirling 1997). Polar bears are most often found where sea ice concentrations exceed 50 percent (Stirling *et al*. 1999,p. 295; Durner *et al*. 2004, pp. 18–19; Durner *et al*. 2006a, p. 24; Durner *et al*. 2009a, p. 51). However, they will use lower sea ice concentrations if this is the only ice that is available over the shallower, more productive waters of the continental shelf (Steve Amstrup, U.S. Geological Survey, pers. comm.; USFWS, unpublished data).

Pregnant female bears typically den along coastal and river banks, pack ice or land during October-November (Lentfer and Hensel 1980; Amstrup and Gardner 1994; Durner et al. 2001). Amstrup and Gardner (1994) reported that 53% of the dens of polar bears radio-collared between 1981 and 1991 were on drifting pack ice, 42% were on land, and 4% were on land-fast ice adjacent to shore. However, in response to recent reductions in the summer extent of sea ice in the Southern Beaufort Sea (Rigor and Wallace 2004; Serreze et al. 2007), female polar bears have exhibited a shift to denning more on land and less on sea ice (Fischbach et al. 2007; Schliebe et al. 2008), so the number of dens that could potentially be disturbed by the proposed activities is estimated to be low. Polar bears also seem more resilient to the loss of a den during fall and early winter than after parturition, probably due to the increased vulnerability of their cubs, during spring (Amstrup 1993).

Twenty-one sightings of 27 polar bears were made during the *Healy* cruise in 2005 (Haley and Ireland 2006). The majority of the sightings were recorded at higher latitudes then where the proposed survey will be conducted, but three sightings of nine individual polar bears were recorded during the 2006 *Healy* cruise between ~73 and 78°N latitude (Haley 2006). Small numbers of polar bears will likely be encountered during the proposed seismic survey

IV. ENVIRONMENTAL CONSEQUENCES OF PROPOSED ACTION

Direct Effects on Marine Mammals and their Significance

The material in this section includes a summary of the anticipated effects (or lack thereof) on marine mammals by the airgun source (28 Bolt airguns with a total discharge volume of 4,330 in^3) to be used during the proposed geophysical survey. A more detailed review of airgun effects on marine mammals appears in Appendix C That Appendix is little changed from corresponding parts of previous EAs and associated IHA Applications concerning seismic survey projects in the following areas: northern Gulf of Mexico; Hess Deep (eastern tropical Pacific); Norwegian Sea; Mid-Atlantic Ocean; Bermuda; SE Caribbean; southern Gulf of Mexico (Yucatan Peninsula); SE Alaska; Blanco Fracture Zone (northeast Pacific); off the Pacific coast of Central America; the Aleutian Islands, Alaska; and across the Arctic Ocean. This section also includes a discussion of the potential impacts of operations by the echo sounder, pinger, and ice profiler to be used during the proposed survey.

Finally, this section includes estimates of the numbers of marine mammals that might be affected by the proposed geophysical survey in the Beaufort Sea in 2010. This section includes a description of the rationale for the estimates of the potential numbers of harassment “takes” during the planned seismic survey.

(1) Summary of Potential Effects of Airgun Sounds

The effects of sounds from airguns might 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 effects (Richardson et al. 1995a). Given the timing for the proposed project, plus mitigation measures to be applied, it is unlikely that there would be any cases of temporary or especially permanent hearing impairment, or non-auditory physical effects. Also, behavioral disturbance could occur at longer distances than auditory effects.

(a) Tolerance

Numerous studies have shown that pulsed sounds from airguns are often readily detectable in the water at distances of many kilometers. For a summary of the characteristics of airgun pulses, see Appendix C(3).

Numerous studies have shown that marine mammals at distances more than a few kilometers from operating seismic vessels often show no apparent response—see Appendix C (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, small odontocetes, and sea otters seem to be more tolerant of exposure to airgun pulses than are baleen whales.

(b) 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 of relevance. Some whales are known to continue calling in the presence of seismic pulses. Their calls 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). Although there has been one report that sperm whales cease calling when exposed to pulses from a very distant seismic ship (Bowles et al. 1994), a more recent study reports that sperm whales off northern Norway continued calling in the presence of seismic pulses (Madsen et al. 2002). That has also been shown during recent work in the Gulf of Mexico (Tyack et al. 2003). Masking effects of seismic pulses are expected to be negligible in the case of the smaller odontocete cetaceans. Also, the sounds important to small odontocetes are predominantly at much higher frequencies than are airgun sounds. Masking effects, in general, are discussed further in Appendix C (4).

(c) Disturbance Reactions

Disturbance includes a variety of effects, including subtle changes in behavior, more conspicuous changes in activities, and displacement. Based on NMFS (2001, p. 9293), 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. 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 the species as a whole. However, if a sound source displaces marine mammals from an important feeding or breeding area for a prolonged period, impacts on the animals could be significant. 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 were present within a particular distance of industrial activities, or exposed to a particular level of industrial sound. That likely overestimates the numbers of marine mammals that are affected in some biologically-important manner.

The sound criteria used to estimate how many marine mammals might be disturbed to some biologically-important degree by a seismic program are based on behavioral observations during studies of several species. However, information is lacking for many species. Detailed studies have been done on humpback, gray, and bowhead whales, and on ringed seals. Less detailed data are available for some other species of baleen whales, sperm whales, small toothed whales, and sea otters.

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 C (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 case of the 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 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 from large arrays of airguns diminish to those levels at distances ranging from 4.5 to 14.5 km from the source. A substantial proportion of the baleen whales within those distances may show avoidance or other strong disturbance reactions to the airgun array. Subtle behavioral changes sometimes become evident at somewhat lower received levels, and recent studies reviewed in Appendix C (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. Bowhead whales migrating west across the Alaskan Beaufort Sea in autumn, in particular, are unusually responsive, with substantial avoidance occurring out to distances of 20–30 km from a medium-sized airgun source (Miller et al. 1999; Richardson et al. 1999; see Appendix C [5]). However, more recent research on bowhead whales (Miller et al. 2005; Lyons et al. 2009; Christie et al. 2009) corroborates earlier evidence that, during the summer feeding season, bowheads are not as sensitive to seismic sources. In summer, bowheads typically begin to show avoidance reactions at a received level of about 160–170 dB re 1 μPa rms (Richardson et al. 1986; Ljungblad et al. 1988; Miller et al. 1999). The ION project will be conducted during October–December when most bowhead whales have migrated south into the Chukchi and Bering seas, therefore significant effects on bowhead whales are not expected.

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 ceased 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. Those findings were generally consistent with the results of experiments conducted on larger numbers of gray whales that were migrating along the California coast, and on observations of Western Pacific gray whales feeding off Sakhalin Island, Russia (Johnson 2002).

Data on short-term reactions (or lack of reactions) of cetaceans to impulsive noises do not necessarily provide information about long-term effects. It is not known whether impulsive noises affect reproductive rate or distribution and habitat use in subsequent days or years. However, gray whales 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). Bowhead whales 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). Populations of both gray whales and bowhead whales grew substantially during this time. This seismic survey is not expected to have a significant impact on gray whales because it is unlikely that they will be present in the study area in October–December.

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 and in Appendix C have been reported for toothed whales. However, systematic work on sperm whales is underway (Tyack et al. 2003), and there is 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 in press).

Seismic operators sometimes see dolphins and other small toothed whales near operating airgun arrays, but in general there seems to be a tendency for most delphinids to show some limited avoidance of seismic vessels operating large airgun systems. However, 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. Nonetheless, there have been indications that small toothed whales sometimes move away, or maintain a somewhat greater distance from the vessel, when a large array of airguns is operating than when it is silent (e.g., Goold 1996a,b,c; Calambokidis and Osmek 1998; Stone 2003). Aerial surveys during seismic operations in the southeastern Beaufort Sea recorded much lower sighting rates of beluga whales within 10-20 km of an active seismic vessel. These results were consistent with the low number of beluga sightings reported by observers aboard the seismic vessel, suggesting that some belugas might be avoiding the seismic operations at distances of 10- 20 km (Miller et al. 2005).

Captive bottlenose dolphins and (of some relevance in this project) beluga whales exhibit changes in behavior when exposed to strong pulsed sounds similar in duration to those typically used in seismic surveys (Finneran et al. 2000, 2002). However, the animals tolerated high received levels of sound (pk–pk level >200 dB re 1 µPa) before exhibiting aversive behaviors. Beluga whales typically migrate south into the Chukchi and Bering seas during winter and thus are unlikely to be exposed to seismic sounds generated by this survey.

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

Pinnipeds—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 C (5). Those studies show that pinnipeds frequently do not avoid the area within a few hundred meters of operating airgun arrays (e.g., Harris et al. 2001; Moulton and Lawson 2002; Miller et al. 2005). However, initial telemetry work suggests that avoidance and other behavioral reactions to small airgun sources may at times be stronger than evident to date from visual studies of pinniped reactions to airguns (Thompson et al. 1998). Even if reactions of the species occurring in the proposed survey area are as strong as those evident in the telemetry study, reactions are expected to be confined to relatively small distances and durations, with no long-term effects on pinniped individuals or populations.

Polar Bears— Airgun effects on polar bears have not been studied. However, polar bears on the ice would be 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. Received levels of airgun sounds are reduced near the surface because of the pressure release effect at the water's surface (Greene and Richardson 1988; Richardson et al. 1995a).

(d) Hearing Impairment and Other Physical Effects

Temporary or permanent hearing impairment is a possibility when marine mammals are exposed to very strong sounds, but there has been no specific documentation of this for marine mammals exposed to sequences of airgun pulses. 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). These exposure levels have also been applied by the USFWS to walrus and polar bear, respectively. Those criteria have been used in defining the safety (shut down) radii planned for the proposed seismic survey. However, those criteria were established before there were any data on the minimum received levels of sounds necessary to cause temporary auditory impairment in marine mammals. As discussed in Appendix C (6) and summarized here,

- the 180 dB criterion for cetaceans is probably quite precautionary, i.e., lower than necessary to avoid temporary threshold shift (TTS), let alone permanent auditory injury, at least for belugas and delphinids.
- the minimum sound level necessary to cause permanent hearing impairment 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.

NMFS is presently developing new noise exposure criteria for marine mammals that account for the now-available scientific data on TTS and other relevant factors in marine and terrestrial mammals (NMFS 2005; D. Wieting *in* http://mmc.gov/sound/plenary2/pdf/plenary2summaryfinal.pdf).

Several aspects of the planned monitoring and mitigation measures for this project are designed to detect marine mammals occurring near the airguns, and to avoid exposing them to sound pulses that might, at least in theory, cause hearing impairment [see Section II(3), MITIGATION MEASURES]. In addition, many cetaceans are likely to show some avoidance of the area with high received levels of airgun sound (see above). In those cases, the avoidance responses of the animals themselves will reduce or (most likely) avoid any possibility of hearing impairment.

Non-auditory physical effects might also occur in marine mammals exposed to strong underwater pulsed sound. Possible types of non-auditory physiological effects or injuries that theoretically might occur in mammals close to a strong sound source include stress, neurological effects, bubble formation, resonance effects, 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. 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, and beaked whales do not occur in the present study area. It is unlikely that any effects of these types would occur during the proposed project given the brief duration of exposure of any given mammal, and the planned monitoring and mitigation measures (see below). The following subsections discuss in somewhat more detail the possibilities of TTS, permanent threshold shift (PTS), and non-auditory physical effects.

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. 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 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.

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. 2005, 2002). Given the available data, the received level of a single seismic pulse might need to be ~210 dB re 1 μPa rms (~221–226 dB pk–pk) in order to produce brief, mild TTS. Exposure to several seismic pulses at received levels near 200–205 dB (rms) might result in slight TTS in a small odontocete, assuming the TTS threshold is (to a first approximation) a function of the total received pulse energy. Seismic pulses with received levels of 200–205 dB or more are usually restricted to a radius of no more than 200 m around a seismic vessel operating a large array of airguns.

For baleen whales, there are no data, direct or indirect, on levels or properties of sound that are required to induce TTS. However, no 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.

In pinnipeds, TTS thresholds associated with exposure to brief pulses (single or multiple) of underwater sound have not been measured. Initial evidence from prolonged exposures suggested that some pinnipeds may incur TTS at somewhat lower received levels than do small odontocetes exposed for similar durations (Kastak et al. 1999; Ketten et al. 2001; *cf.* Au et al. 2000). For harbor seal, which is closely related to the ringed seal, TTS onset apparently occurs at somewhat lower received energy levels than for odontocetes.

A marine mammal within a radius of ≤100 m around a typical large array of operating airguns might be exposed to a few seismic pulses with levels of ≥205 dB, and possibly more pulses if the mammal moved with the seismic vessel. Several of the considerations that were relevant in assessing the impact of previous seismic surveys with arrays of airguns are directly applicable here:

- "Ramping up" (soft start) is standard operational protocol during startup of airgun arrays in many jurisdictions. Ramping up involves starting the airguns in sequence, usually commencing with a single airgun and gradually adding additional airguns. This practice will be employed when the airgun array is operated during the propose survey.
- It is unlikely that 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. Furthermore, few cetaceans are expected to be present in the study area in October–December.
- With a large array of airguns, TTS would be most likely in any odontocetes that bow-ride or otherwise linger near the airguns. However, no species that occur within the project area are expected to bow-ride.

NMFS (1995, 2000) concluded that cetaceans and pinnipeds should not be exposed to pulsed underwater noise at received levels exceeding, respectively, 180 and 190 dB re 1 µPa (rms). Initial safety and disturbance radii for the sound levels produced by the airgun array have been modeled. The planned survey will use an airgun source composed of 28 airguns with a total discharge volume of 4330 in^3. The modeled 190 and 180 dB distances from the array were most likely to be 670 and 2850 m, respectively, in shallow water (<100 m) where sound propagation is expected to be greatest. These radii will be used for mitigation purposes until results of field measurements are available early during the exploration activities. Furthermore, established 190 and 180 dB re 1 µPa (rms) criteria are ***not*** considered to be the levels above which TTS might occur. Rather, they are 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 unless odontocetes are exposed to airgun pulses much stronger than 180 dB re 1 µPa rms. Since no bow-riding species occur in the study area, it is unlikely such exposures will occur.

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.

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 TTS, there has been further speculation about the possibility that some individuals occurring very close to airguns might incur PTS. Single or occasional occurrences of mild TTS are not indicative of permanent auditory damage in terrestrial mammals. 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 might occur at a received sound level at least several decibels above that inducing mild TTS if the animal were exposed to the strong sound pulses with very rapid rise time—see Appendix C (6).

It is highly unlikely that marine mammals could receive sounds strong enough (and over a sufficient duration) to cause permanent hearing impairment during a project employing the airgun sources planned here. In the proposed project, marine mammals are unlikely to be exposed to received levels of seismic pulses strong enough to cause TTS. Given the higher level of sound necessary to cause PTS, it is even less likely that PTS could occur. In fact, even the levels immediately adjacent to the airgun may not be sufficient to induce PTS, especially because a mammal would not be exposed to more than one strong pulse unless it swam immediately alongside the airguns for a period longer than the inter-pulse interval. Baleen whales generally avoid the immediate area around operating seismic vessels. The planned monitoring and mitigation measures, including visual monitoring, power downs, and shut downs of the airguns when mammals are seen within the "safety radii", will minimize the already-minimal 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, and other types of organ or tissue damage. However, studies examining such effects are very limited. If any such effects do occur, they probably would be limited to unusual situations when animals might be exposed at close range for unusually long periods. It is doubtful that any single marine mammal would be exposed to strong seismic sounds for sufficiently long that significant physiological stress would develop. That is especially so in the case of the proposed project where the airgun configuration focuses most energy downward, the ship is moving at 4–5 knots, and for the most part, the tracklines will not "double back" through the same area.

Until recently, it was assumed that diving marine mammals are not subject to the bends or air embolism. This possibility was first explored at a workshop (Gentry [ed.] 2002) held to discuss whether the stranding of beaked whales in the Bahamas in 2000 (Balcomb and Claridge 2001; NOAA and USN 2001) might have been related to bubble formation in tissues caused by exposure to noise from naval sonar. However, the opinions were inconclusive. Jepson et al. (2003) first suggested a possible link between mid-frequency sonar activity and acute and chronic tissue damage that results from the formation *in vivo* of gas bubbles, based on the beaked whale stranding in the Canary Islands in 2002 during naval exercises. Fernández et al. (2005a) showed those beaked whales did indeed have gas bubble-associated lesions as well as fat embolisms. Fernández et al. (2005b) also found evidence of fat embolism in three beaked whales that stranded 100 km north of the Canaries in 2004 during naval exercises. Examinations of several other stranded species have also revealed evidence of gas and fat embolisms (e.g., Arbelo et al. 2005; Jepson et al. 2005a; Méndez et al. 2005). Most of the afflicted species were deep divers. There is speculation that gas and fat embolisms may occur if cetaceans ascend unusually quickly when exposed to aversive sounds, or if sound in the environment causes the destabilization of existing bubble nuclei (Potter 2004; Arbelo et al. 2005; Fernández et al. 2005a; Jepson et al. 2005b). Even if gas and fat embolisms can occur during exposure to mid-frequency sonar, there is no evidence that that type of effect occurs in response to airgun sounds. Also, most evidence for such effects have been in beaked whales, which do not occur in the proposed study area.

In general, little is known about the potential for seismic survey sounds to cause auditory impairment or other physical effects in marine mammals. Available data suggest that such effects, if they occur at all, would be limited to short distances and probably to projects involving large arrays of airguns. However, the available data do not allow for meaningful quantitative predictions of the numbers (if any) of marine mammals that might be affected in those ways. Marine mammals that show behavioral avoidance of seismic vessels, including most baleen whales, some odontocetes (including belugas), and some pinnipeds, are especially unlikely to incur auditory impairment or other physical effects. Also, the planned monitoring and mitigation measures include power downs and shut downs of the airguns, which will reduce any such effects that might otherwise occur.

(e) Strandings and Mortality

Marine mammals close to underwater detonations of high explosive can be killed or severely injured, and the auditory organs are especially susceptible to injury (Ketten et al. 1993; Ketten 1995). Airgun pulses are less energetic and have slower rise times, and there is no proof 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, 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. Appendix C (6.3) provides additional details.

Seismic pulses and mid-frequency sonar pulses are quite different. Sounds produced by airgun arrays are broadband with most of the energy below 1 kHz. Typical military mid-frequency sonars operate at frequencies of 2–10 kHz, generally with a relatively narrow bandwidth at any one time. Thus, it is not appropriate to assume that there is a direct connection between the effects of military sonar and seismic surveys on marine mammals. However, evidence that sonar pulses can, in special circumstances, lead to physical damage and mortality (NOAA and USN 2001; Jepson et al. 2003; Fernández et al. 2005a), even if only indirectly, suggests that caution is warranted when dealing with exposure of marine mammals to any high-intensity pulsed sound.

In May 1996, 12 Cuvier's beaked whales stranded along the coasts of Kyparissiakos Gulf in the Mediterranean Sea. That stranding was subsequently linked to the use of low- and medium-frequency active sonar by a North Atlantic Treaty Organization (NATO) research vessel in the region (Frantzis 1998). In March 2000, a population of Cuvier's beaked whales being studied in the Bahamas disappeared after a U.S. Navy task force using mid-frequency tactical sonars passed through the area; some beaked whales stranded (Balcomb and Claridge 2001; NOAA and USN 2001).

In September 2002, a total of 14 beaked whales of various species stranded coincident with naval exercises in the Canary Islands (Martel n.d.; Jepson et al. 2003; Fernández et al. 2003). Also in Sept. 2002, there was a stranding of two Cuvier's beaked whales in the Gulf of California, Mexico, when the L-DEO vessel, *Maurice Ewing,* was operating a 20-airgun, 8,490 in^3 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, that plus the incidents involving beaked whale strandings near naval exercises suggests a need for caution in conducting seismic surveys in areas occupied by beaked whales. However, no beaked whales are found within the proposed study area and the planned monitoring and mitigation measures are expected to minimize any possibility for mortality of other species.

(f) Possible Effects of Echo Sounder Signals

The *Geo Explorer's* echo sounder (i.e., fathometer), Simrad EA 600, will be operated almost continuously during the planned survey. The downward-facing single-beam Simrad EA 600 operates at frequencies ranging from 12 to 710 kHz with a maximum output power of 2 kW. It is expected that the echo sounder will be operated at 38 kHz. Details about the Simrad EA 600 were provided in Section II (2)(f). Sounds from the echo sounder are very short pulses, depending on water depth. Most of the energy in the sound pulses emitted by the echo sounder is at high frequencies. The downward-facing single beam is narrow, and any given mammal at depth near the trackline would be in the main beam for only a fraction of a second. Therefore, marine mammals that encounter the Simrad EA 600 at close range are unlikely to be subjected to repeated pulses because of the narrow beam, and will receive only limited amounts of pulse energy because of the short pulses. The animal would have to pass the transducer at close range and be swimming at speeds similar to the vessel in order to be subjected to sound levels that could cause TTS.

Navy sonars that have been linked to avoidance reactions and stranding of cetaceans (1) generally are more powerful than the Simrad EA 600 echo sounder, (2) have longer pulse duration, and (3) are directed close to horizontally vs. downward. Therefore, the area of possible influence of the echo sounder is much smaller. Marine mammals that encounter the echo sounder at close range are unlikely to be subjected to repeated pulses because of the narrow beam, and will receive only small amounts of pulse energy because of the short pulses.

Masking

The echo sounder produces sounds within the frequency range used by odontocetes that may be present in the survey area and within the frequency range heard by pinnipeds; however communication for these species will not be masked appreciably given the low duty cycle and the brief period when an individual mammal is likely to be within the beam. Furthermore, the main operating frequency of the echo sounder (38 kHz) will not overlap with the predominant frequencies in baleen whale calls, further reducing any potential for masking in that group.

Behavioral Responses

Behavioral reactions of free-ranging marine mammals to military and other sonars 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. Also, Navy personnel have described observations of dolphins bow-riding adjacent to bow-mounted mid-frequency sonars during sonar transmissions. During exposure to a 21–25 kHz whale-finding sonar with a source level of 215 dB re 1 µPa@ 1m, gray whales showed slight avoidance (~200 m) behavior (Frankel 2005).

However, all of those observations are of limited relevance to the present situation. Pulse durations from the Navy sonars were much longer than those of the echo sounder to be used during the proposed study, and a given mammal would have received many pulses from the naval sonars. During ION's 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.

Captive bottlenose dolphins and a beluga whale exhibited changes in behavior when exposed to 1 s pulsed sounds at lower frequencies (3, 10 and 20 kHz) than those expected to be emitted by the echo sounder to be used by ION (38 kHz). 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 echo sounder.

We are not aware of any data on the reactions of pinnipeds to sonar sounds at frequencies similar to those of the echo sounder. Based on observed pinniped responses to other types of pulsed sounds, and the likely brevity of exposure to the echo sounder, pinniped reactions are expected to be limited to startle or otherwise brief responses of no lasting consequence to the animals.

Polar bears would not occur below the *Geo Explorer* or elsewhere at sufficient depth to be in the main beam of the echo sounder, so would not be affected by the sounds.

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 echo sounder would not result in a "take" by harassment.

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 echo sounder proposed for use by ION are quite different from sonars used for navy operations. Pulse duration of the echo sounder is very short relative to the naval sonars. Also, at any given location, an individual cetacean or pinniped would be in the beam of the echo sounder for much less time given the generally downward orientation of the beam and its narrow beamwidth. (Navy sonars often use near-horizontally-directed sound.) Those factors would all reduce the sound energy received from the echo sounder relative to that from the sonars used by the Navy. Polar bears would not occur in the main beam of the sonar.

(g) Possible Effects of Ice Profiler Signals

Ice Profiler (ASL Ice Profiler IPS5)

The ice profiler (IPS5) will be mounted on the hull of the *Geo Explorer* and direct a narrow beam (1.8°) forward to provide information on ice conditions. Details about the equipment were provided in Section II (2)(f). The ice profiler produces sound pulses of programmable duration (68 ms long is standard) every 1 to 2 s. The energy in the sound pulses emitted by this ice profiler is high frequency (420 kHz), with a nominal source level of 228 dB re 1 µPa @ 1m. Because the 420 kHz signals do not overlap with the hearing frequencies of any marine mammal, the ice profiler will not have an effect on marine mammal communication or behavior. Beluga whale is the only odontocete that could potentially be encountered in the area of the proposed survey; however belugas hear sounds ranging from 1.2 to 120 kHz, which is well below the ice profilers 420 kHz signals (Fay 1988).

(h) Possible Effects of Icebreaking Activities

Limited information is available about the effects of icebreaking ships on most species of marine mammals. Early concerns arose due to proposals (which were never realized) to conduct shipping of oil and gas in the Arctic via large icebreakers (Peterson 1981). Smaller icebreaking ships have been used by the oil and gas industry in the Beaufort and Chukchi seas to extend the offshore drilling period in support of offshore drilling, and several icebreakers or strengthened cargo ships have been used in the Russian northern sea route as well as elsewhere in the Arctic and Antarctic (Armstrong 1984; Barr and Wilson 1985; Brigham 1985).

The primary concern regarding icebreaking activities involves the production of underwater sound (Richardson et al. 1995a). Estimated source levels of the ice-breaking cargo vessel MV *Arctic* may be detectable by seals under fast ice at distances up to 20-35 km (Davis and Malme 1997). However, icebreaking activities may also have non-acoustic effects such as the potential for causing injury, ice entrapment of animals that follow the ship, and disruption of ice habitat (reviewed *in* Richardson et al. 1989:315). The species of marine mammals that may be present and the nature of icebreaker activities are strongly influenced by ice type. Some species are more common in loose ice near the margins of heavy pack ice while others appear to prefer heavy pack ice. Propeller cavitation noise of icebreaking ships in loose ice is likely similar to that in open water while noise is expected to be much greater in areas of heavier pack ice or thick landfast ice where ship speed will be reduced, power levels will be higher, and there will be greater propeller cavitation (Richardson et al. 1995a).

Beluga Whales—Erbe and Farmer (1998) measured masked hearing thresholds of a captive beluga whale. They reported that the recording of a Canadian Coast Guard ship, *Henry Larsen*, ramming ice in the Beaufort Sea, masked recordings of beluga vocalizations at a noise-to-signal pressure ratio of 18 dB. That occurred when the noise pressure level was eight times as high as the call. In linear units, the ramming noise was 8 times as strong as the call (Erbe and Farmer 1998). A similar study using a software model to estimate the zones of impact around icebreakers affecting beluga whales in the Beaufort Sea predicted that masking of beluga communication signals by ramming noise from an icebreaker could occur within 40-71 km, depending on the location. However, arctic beluga whales have shown avoidance of icebreakers when first detected (Erbe and Farmer 2000; see below), so individuals are unlikely to get close enough for potentially harmful effects such as masking to occur. In addition, vocal behavior of beluga whales in the St, Lawrence in the presence of a ferry and a small motorboat have shown that belugas can change the types of calls they use, as well as shift the mean call frequency up during noise exposure (Lesage et al. 1999). Therefore, masking effects of icebreaking activities on beluga whales are expected to be negligible for the proposed survey.

In 1991 and 1994 in the Alaskan Beaufort Sea, Richardson et al. (1995b) recorded reactions of beluga and bowhead whales to playbacks of underwater propeller cavitation noise from the icebreaker *Robert Lemeur* operating in heavy ice. Migrating belugas were observed close to the playback projectors on three dates, but interpretable data were only collected on 17 groups for two of these occasions. A minimum of six groups apparently altered their path in response to the playback, but whales approached within a few hundred (and occasionally tens of) meters before exhibiting a response. Icebreaker sounds were estimated at 78-84 dB re 1µPa in the 1/3-octave band centered at 5000 Hz, or 8-14 dB above ambient sound levels in that band, for the six groups that reacted. The authors estimated that reactions at this level would be estimated to occur at distances of ~10 km from an operating icebreaker.

Beluga whales are expected to avoid icebreaking vessels at distances of ~10 km. The impacts of icebreaking associated with the seismic program on the behavior of belugas are expected to be temporary, lasting only as long as the activity is on-going, and would not have any effect on the beluga population.

Bowhead Whales— In 1991 and 1994 in the Alaskan Beaufort Sea, Richardson et al. (1995b) recorded reactions of beluga and bowhead whales to playbacks of underwater propeller cavitation noise from the icebreaker *Robert Lemeur* operating in heavy ice. Bowhead whales migrating in the nearshore appeared to tolerate exposure to projected icebreaker sounds at received levels up to 20 dB or more above ambient noise levels. However, some bowheads appeared to divert their paths to remain further away from the projected sounds, particularly when exposed to levels >20 dB above ambient. Turning frequency, surface duration, number of blows per surfacing, and two multivariate indices of behavior were significantly correlated with the signal-to-noise ratio >20 dB (and as low as 10 dB for turning frequency). The authors suggested that bowheads may commonly react to icebreakers at distances up to 10-50 km, but note that reactions were very dependent on several variables not controlled in the study.

There are few other studies on the reactions of baleen whales to icebreaking activities. During fall 1992, migrating bowhead whales apparently avoided (by at least 25 km) a drillsite that was supported near-daily by intensive icebreaking activity in the Alaskan Beaufort Sea (Brewer et al 1993). However, bowheads also avoided a nearby drillsite in the fall of another year that had little icebreaking support (LGL and Greenridge 1987). Thus, level of contribution from icebreaking, ice concentration, and drilling noise resulting in bowhead responses is unknown.

Bowhead whales are expected to avoid vessels that are underway, including icebreakers. The impacts of icebreaking on the behavior of bowheads are likely to occur only if bowheads are still in the western portion of the study area although most bowheads will likely have passed through the survey area prior to the start of survey activities. The effects of icebreaking activities on bowhead whales are expected to be minor and short-term.

Pinnipeds— Reactions of walruses to icebreakers are probably described more thoroughly than are reactions by other pinnipeds. When comparing the reaction distances of walrus to icebreaking ships vs. other ships traveling in open water, Fay et al. (1984) found that walrus reacted at longer distances to icebreakers. They were aware of the icebreaker when it was >2 km away, and females with pups entered the water and swam away when the ship was ~1 km away while adult males did so at distances of 0.1 to 0.3 km. However, it was also noted that some walruses, ringed seals, and bearded seals also scrambled onto ice when an icebreaker was oriented toward them.

In another study of 202 walrus groups observed on ice floes during icebreaking activities, 32% dove into the water and 6% became alert while on the ice (Brueggeman et al. 1990, 1991, 1992). Concurrent aerial surveys indicated that walruses hauling out on ice floes may have avoided icebreaking activities within 10-15 km (Brueggeman et al. 1990).

Ringed and bearded seals on pack ice approached by an icebreaker typically dove into the water within 0.93 km (0.58) of the vessel, but tended to be less responsive when the same ship was underway in open water (Brueggeman et al. 1992). In another study, ringed and harp seals remained on the ice when an icebreaker was 1-2 km away, but seals often dove into the water when closer to the icebreaker (Kanik et al. 1980 *in* Richardson et al. 1995a). Ringed seals have also been seen feeding among overturned ice floes in the wake of icebreakers (Brewer et al. 1993).

Seals swimming are likely to avoid approaching vessels by a few meters to a few tens of meters, while some “curious” seals are likely to swim toward vessels. Seals hauled out on ice also show mixed reaction to approaching vessels/icebreakers. Seals are likely to dive into the water if the icebreaker comes within 1 km. The impact of vessel traffic on seals is expected to be negligible.

Polar Bears—Little information is available on the reactions of polar bears to icebreaking activities. Polar bears apparently show little reaction to shipping, with some bears briefly walking, running, or swimming away in a localized area (Fay et al. 1984) or others showing no reaction (Brueggeman et al. 1991). It is likely that the ION icebreaker will encounter polar bears; however, the impact of vessel traffic on polar bears is expected to be negligible.

(2) Mitigation Measures

Several mitigation measures are built into the planned seismic survey as an integral part of the activities, as described in Section II (3). Those measures include the following: conducting the study during a period when few bowheads and other whale species are likely to be present, at least one observer maintaining a visual watch during ongoing daytime operations and any nighttime start ups or ramp ups of the airguns, power downs or shut downs when mammals are detected in or about to enter designated safety zones, and no start ups of the airgun array unless the full 180 dB radius is visible.

Previous and subsequent analysis of potential impacts takes account of the 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 May be "Taken by Harassment"

All anticipated takes would be "takes by harassment" 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 C, there is no specific information demonstrating that injurious "takes" would occur even in the absence of the planned mitigation measures.) The sections below describe methods used to estimate "take by harassment" and present estimates of the numbers of marine mammals that might be affected during the proposed seismic study in the Arctic Ocean. The estimates are based on data obtained during marine mammal surveys in the Beaufort Sea and on estimates of the sizes of the areas where effects could potentially occur. In some cases, these estimates were made from data collected from regions and habitats that differed from the proposed project area. Adjustments to reported population or density estimates were made on a case by case basis to account for differences between the source data and the available information on the distribution and abundance of the species in the project area. This section provides estimates of the number of potential "exposures" to sound levels ≥160 dB re 1 µPa (rms).

Although several systematic surveys of marine mammals have been conducted in the southern Beaufort Sea during spring and summer, few data (systematic or otherwise) are available on the distribution and numbers of marine mammals during the early winter period of this survey, particularly in the northern Beaufort Sea. The main sources of distributional and numerical data used in deriving the estimates are described in the next subsection. There is some uncertainty about how representative those data are and the assumptions used below to estimate the potential "take by harassment". However, the approach used here is accepted by NMFS as the best available at this time. The following estimates are based on a consideration of the number of marine mammals that might be disturbed appreciably by ~7250 line kilometers of seismic surveys across the Beaufort Sea and, to a lesser extent, the northern Chukchi Sea.

(a) Marine Mammal Density Estimates

This section describes the estimated densities of marine mammals that may occur in the survey area. The area of water that may be ensonified to ≥160 dB is described below in the section *Potential Number of "Takes by Harassment."* There is no evidence that avoidance at received sound levels of ≥160 dB would have significant effects on individual animals or that the subtle changes in behavior or movements would "rise to the level of taking" according to guidance by the NMFS (NMFS 2001). Any changes in behavior caused by sounds at or near the 160 dB rms level would likely fall within the normal variation in such activities that would occur in the absence of this survey.

The survey has been designed to minimize interactions with marine mammals by planning to conduct work in areas where relative density of marine mammals is expected to be the lowest. The survey will begin in offshore waters (>1000 m) of the eastern US Beaufort Sea (east survey area; Fig. 1) in early October. Weather and ice permitting, the waters <1000 m deep will not be surveyed until mid-October, in order to avoid migrating bowhead whales. The western US Beaufort Sea (west survey area) is not expected to be surveyed until late October through December.

Densities were calculated for habitats that are specific to cetaceans and pinnipeds. For cetaceans, densities were estimated for areas of water depth <200 m, 200–1000 m, and >1000 m, which approximately correspond to the continental shelf, the continental slope, and the abyssal plain, respectively. Separate densities of both cetacean and pinnipeds were also estimated for the east and west survey areas within each water depth category. However, pinniped densities in the west survey area <200 m water depth category were further sub-divided into <35 m and 35–200 m categories. This was done because the west survey area is not expected to be surveyed until November–December, and based on historic sea ice data (NOAA National Ice Center, available online at www.natice.noaa.gov), it is expected that sea ice will be present in the west survey area at that time. Past studies have found that seal density in ice-covered areas is different in areas with water depth <35 m and >35 m (Frost et al. 2004, Moulton et al. 2002), therefore densities were calculated separately for these water depths.

To provide some allowance for uncertainties, "maximum estimates" as well as "best (average) estimates" of the numbers potentially affected were derived. For a few marine mammal species, several density estimates were available, and in those cases, the mean and maximum estimates were calculated from the survey data. When the seismic survey area is on the edge of the range of a species at this time of year, we assumed that the average density along the seismic trackline will be 0.10× the density from the available survey data.

Detectability bias, quantified in part by $f(0)$, is associated with diminishing sightability with increasing lateral distance from the survey trackline. Availability bias, $g(0)$, refers to the fact that there is <100% probability of sighting an animal that is present along the survey trackline. Some sources below included these correction factors in the reported densities and the best available correction factors were applied to reported results when they had not already been included. Details regarding the application of correction factors are provided for each species.

Cetaceans

Beluga density estimates were calculated using aerial survey data collected in October in the Beaufort Sea by the Minerals Management Service 1997–2004. The surveys covered the entire Alaskan Beaufort Sea coastline from 158° to 140° W longitude and from the coastline north to 72° N latitude, encompassing the entire continental shelf. As described above, density estimates were calculated separately for the east and west survey areas. For the east survey area, the mean density estimate for areas of 200–1000 m water depth (0.0408 belugas per km^2; Table 3) was based on 97 on transect sightings collected over a total of 32,229 km of survey effort. The effort for each survey was found in MMS reports (Treacy 1998, Treacy 2000, Treacy 2002, Monnett and Treacy 2005), and the corresponding sightings were those coded as "on transect" in the MMS database (MMS 2010). Average group size calculated from the aforementioned sightings data was 4.89 individuals. A $f(0)$ value of 2.326 was applied that was calculated using beluga whale data collected in the Canadian Beaufort Sea (Innes et al. 2002). A $g(0)$ value of 0.419 was used that represents a combination of $g_a(0) = 0.55$ (Innes et al. 2002) and $g_d(0) = 0.762$ (Harwood et al. 1996). This density estimate was applied to areas of 200–1000 m water depth because the majority (97%) of the beluga sightings occurred beyond the 200 m depth contour

(Treacy 1998, Treacy 2000, Treacy 2002, Monnett and Treacy 2005). For all water depth and survey area categories, the maximum beluga density estimates represent the mean estimates multiplied by four to allow for chance encounters with unexpected large groups of animals or overall higher densities than expected.

TABLE 3. Expected densities of cetaceans in the Beaufort Sea in October–December by water depth and survey area. Species listed as endangered are in italics.

	<200 m		**200–1000 m**		**>1000 m**	
Species	**Average density (#/km^2)**	**Maximum density (#/km^2)**	**Average density (#/km^2)**	**Maximum density (#/km^2)**	**Average density (#/km^2)**	**Maximum density (#/km^2)**
East survey area						
Odontocetes						
Beluga	0.0016	0.0065	0.0408	0.1632	0.0155	0.0620
Harbor porpoise	0.0001	0.0004	0.0001	0.0004	0.0001	0.0004
Mysticetes						
Bowhead whale	0.0257	0.1027	0.0008	0.0031	0.0001	0.0004
Gray whale	0.0001	0.0004	0.0001	0.0004	0.0001	0.0004
Minke whale	0.0001	0.0004	0.0001	0.0004	0.0001	0.0004
Humpback whale	0.0001	0.0004	0.0001	0.0004	0.0001	0.0004
West survey area						
Odontocetes						
Beluga	0.0002	0.0007	0.0041	0.0163	0.0016	0.0062
Harbor porpoise	0.0001	0.0004	0.0001	0.0004	0.0001	0.0004
Mysticetes						
Bowhead whale	0.0026	0.0103	0.0001	0.0004	0.0001	0.0004
Gray whale	0.0001	0.0004	0.0001	0.0004	0.0001	0.0004
Minke whale	0.0001	0.0004	0.0001	0.0004	0.0001	0.0004
Humpback whale	0.0001	0.0004	0.0001	0.0004	0.0001	0.0004

Densities for the other water depth bins in the east survey area were calculated as follows. There were approximately 4% and 38% as many beluga sightings recorded in the <200 m and >1000 m water depth bins, respectively, compared to the number of sightings in the 200–1000 m water depth bin (MMS 2010). Density estimates for the <200 m and >1000 m categories were therefore estimated as 4% and 38%, respectively, of the 200–1000 m density. The findings of Moore et al. (2000a,b) further support the use of lower density estimates for the continental shelf. Moore et al. (2000a) found that in autumn, belugas were seen far more often than expected in continental slope waters and far less often than expected in inner shelf habitat. Moore et al. (2000b) reported that selection ratios indicated that belugas avoid inner shelf habitat in all ice conditions.

Beluga density estimates for the west survey area, which is planned to be surveyed beginning in November, represent the east survey area estimates multiplied by 0.10 because the Beaufort Sea is considered to be at the edge of the species' range in November–December. Belugas typically migrate into the Bering Sea for the winter (Angliss and Allen 2009) and are not expected to be present in the study area in high numbers in November–December. Satellite tagging data supports beluga migration out of the Beaufort Sea in October–November (Suydam et al 2005).

Bowhead whale density estimates were calculated using aerial survey data collected in October in the Beaufort Sea by the Minerals Management Service 1997–2004 (Treacy 1998, Treacy 2000, Treacy 2002, Monnett and Treacy 2005) and industry (2006–2008; Christie et al. 2009). The data included 258 on transect sightings collected over 35,268 km of effort. The effort for each MMS survey was found in MMS reports (Treacy 1998, Treacy 2000, Treacy 2002, Monnett and Treacy 2005), and the corresponding sightings were coded as "on transect" in the MMS database (MMS 2010). A mean group size of 2.19 individuals per sighting was calculated from the aforementioned sightings data. A $f(0)$ correction factor of 2.27 was used that represented a weighted average of the $f(0)$ values applied to each of the MMS flights (Richardson and Thomson 2002). A $g(0)$ value of 0.0727 was used that represents a combination of $g_a(0) = 0.144$ and $g_d(0) = 0.505$ correction factors reported in Richardson and Thomson (2002). The resulting density estimate (0.2567 whales per km^2; Table 3) represents the best estimate for early October for areas of <200 m water depth, and is referred to below as the reference density for bowhead whales. In all water depth and survey area categories, bowhead maximum density estimates represent the mean estimates multiplied by four to allow for chance encounters with unexpected large groups of animals or overall higher densities than expected. A factor of four is approximately equivalent to the upper 95% confidence interval for bowhead whale densities reported in Savarese et al. (2009).

Because bowhead whale density is typically higher in shallower nearshore waters of the Beaufort Sea in early October, the survey has been designed to start in the eastern US Beaufort Sea in waters deeper than 1000 m (ice conditions permitting), where bowhead density is expected to be much lower. Survey activity in shallower waters will proceed from east to west starting later in October as bowhead whales migrate west out of the Beaufort Sea. The nearshore lines in the east survey area will be surveyed during late October. Density in the east survey area in waters <200 m deep was estimated by taking ten percent of the reference density. This adjustment was based on data from Miller et al. (2002) that showed a ~90% decrease in bowhead whale abundance in the eastern Beaufort Sea from early to late October.

Bowhead whale densities in intermediate (200–1000 m) and deep (>1000 m) water depths in the east survey area are expected to be relatively low. Ninety-seven percent of sightings recorded by MMS aerial surveys 1997–2004 occurred in areas of water depth <200 m (Treacy 1998, Treacy 2000, Treacy 2002, Monnett and Treacy 2005). Therefore, density estimates for areas of water depth 200–1000 m were estimated to be ~3% of the values for areas with depth <200 m. This is further supported by Mate et al. (2000), who found that 87% of locations from satellite-tagged bowhead whales occurred in areas of water depth <100 m. In areas with water depth >1000 m, approximately 4,225 km of aerial survey effort occurred during October 1997–2004, however no bowhead sightings were recorded. The effort occurred over eight years, so it is unlikely that this result would have been influenced by ice cover or another single environmental variable that might have affected whale distribution in a given year. Therefore, a minimal density estimate (0.0001 whales/km^2) was used for areas with water depth >1000 m.

Several sources were used to estimate bowhead whale density in the west survey area, which is expected to be surveyed beginning in late October or early November. Mate et al. (2000) found that satellite-tagged bowhead whales in the Beaufort Sea travelled at an average rate of 88 km per day. At that rate, an individual whale could travel across the extent of the east survey area in four days and across the entire east-west extent of the survey area in ten days if it did not stop to feed during its migration, as bowhead whales sometimes do (Christie et al. 2009). Also, Miller et al. (2002) presented a 10-day moving average of bowhead whale abundance in the eastern Beaufort Sea using data from 1979–2000 that showed a decrease of ~90% from early to late October. Based on these data, it is expected that whales that had been in the east survey area during early October would likely have migrated beyond the west survey area by November–December. In addition, kernel density estimates generated from satellite-tagging data indicated that few whales were present in the proposed survey area in November (near Point Barrow), and no whales were present in December (ADFG 2009). Therefore, density estimates for the <200 m and 200–1000 m water depth categories in the west survey area were estimated to be one tenth of those estimates for the east survey area. Minimal density estimates (0.0001 whales/km^2) were used for areas of water depth >1000 m.

Other cetacean species are not expected to be present in the area at the time of the planned survey. These species, including gray whale, humpback whale, fin whale, Minke whale, and harbor porpoise, typically migrate during autumn and are expected to be south of the Beaufort Sea by the October–December period. Authorization for minimal takes of other cetacean species that are known to occur in the Beaufort Sea during the summer have been requested in case of a chance encounter of a few remaining individuals.

Pinnipeds

In polar regions, most pinnipeds are associated with sea ice and census methods count pinnipeds when they are hauled out on ice. In the Beaufort Sea, surveys typically occur in spring when ringed seals emerge from their lairs (Frost et al. 2004). Depending on the species and study, a correction factor for the proportion of animals hauled out at any one time may or may not have been applied (depending on whether an appropriate correction factor was available for the particular species and area). By applying a correction factor, the total density of the pinniped species in an area can be estimated. Only the animals in water would be exposed to the pulsed sounds from the airguns, however densities that are presented generally represent all animals in the area. Therefore, only a fraction of the pinnipeds present in areas where ice is present and can support hauled-out animals would be exposed to seismic sounds during the proposed seismic survey.

Ringed seal density for the east survey area for waters <1000 m deep was estimated using vessel-based data collected in the Beaufort Sea during autumn (Sep–Oct) 2006–2008 and reported by Savarese et al. (2009; Table 4). Correction factors for sightability and availability were used when the authors calculated the estimates, so no adjustments were required. For the east survey area for waters >1000 m deep, few data on seal distribution are available. Harwood et al. (2005) recorded a ringed seal sighting in the Beaufort Sea in an area where water depth was >1000 m in September–October 2002 during an oceanographic cruise. It is therefore possible that ringed seals would occur in those areas, and their presence would likely be associated with ephemeral prey resources. If a warm surface eddy formed that concentrated prey in offshore areas at depths that would be possible for ringed seals to access, it is possible that seals would be attracted to it. A warm eddy was found in the northern Beaufort Sea in October 2002 in an area where water depth was >1000 m (Crawford 2010), so it is possible that such an oceanographic feature might develop again and attract seals offshore. However, it is unclear whether such a feature would attract many seals, especially since the marine mammal observers present on the ship in 2002 did not observe very many seals associated with the offshore eddy that they recorded. Therefore, in the absence of standardized survey data, minimal density estimates (0.0001 seals/km^2) were used in areas where water depth is >1000 m. For all water depth categories, the maximum ringed seal estimates represent the mean estimates multiplied by two to allow for chance encounters with unexpected large groups of animals or overall higher densities than expected. A factor of two is approximately equivalent to the upper 95% confidence interval reported for ringed seal densities in Savarese et al. (2009).

Habitat zones and associated densities were defined differently in the west survey area, which will be surveyed in November–December, because more ice is expected to be encountered at that time than in October (NOAA National Ice Center: www.natice.noaa.gov). The density estimates for the west survey area were calculated using aerial survey data collected by Frost et al. (2004) in the Alaskan Beaufort Sea during the spring. A *g*(0) correction factor of 0.60 from tagging data reported by Bengtson et al. (2005) was used to adjust all density estimates from Frost et al. (2004) described below. Seal distribution and density in spring, prior to breakup, are thought to reflect distribution patterns established earlier in the year (ie. during the winter months; Frost et al. 2004). Density estimates were highest (1.00–1.33 seals/km^2) in areas of water depth 3–35 m, and decreased (0–0.77 seals/km^2) in water >35 m deep. The mean density estimate used for areas with water depth <35 m (Table 5) was estimated using an average of the pack ice estimates modeled by Frost et al. (2004). The maximum estimate for the same area is the maximum observed density for areas of water depth 3–35 m in Frost et al. (2004). The mean density estimate used for areas with 35–200 m water depth is the modeled value for water depth >35 m from Frost et al. (2004). The maximum estimate is the maximum observed density for areas with >35 m water depth in Frost et al. (2004). Because ringed seal density tends to decrease with increasing water depth (Frost et al. 2004, Moulton et al. 2002), ringed seal density was estimated to be minimal in areas of >200 m water depth.

Other pinniped species are not expected to be present in the study area during the period of this survey. Bearded and spotted seals would be present in the area during summer, but they migrate into the Chukchi and Bering seas during fall (Angliss and Allen 2009). Few satellite-tagging studies have been conducted on these species in the Beaufort Sea, and winter surveys have not been conducted. Therefore, it is possible that some individuals, bearded seals in particular, may be present in the survey area. In the absence of better information from the published literature, minimal density estimates were used for all areas and water depth categories for these species, with the estimates for bearded seals assumed to be higher than those for spotted and ribbon seals, and Pacific walrus (Tables 3 & 4).

Polar Bear

There are 69 recorded sightings of ***polar bear*** in the MMS aerial survey databasse (MMS 2010) during October of 1997–2004 (the same period for which survey effort was available and used for bowhead and beluga density estimates above). Of these 69 sightings, eight were observed in “open water”, although all of these sightings occurred near barrier islands. There were six sightings of polar bear recorded offshore away from barrier islands, all of which were noted as “on ice”. One sighting of a polar bear swimming offshore and away from ice was recorded during industry aerial surveys off Camden Bay in 2006 (Christie et al. 2009). Given the low occurrence of polar bear sightings offshore and in the water (where they would be exposed to seismic sounds) minimal densities have been used to account for chance encounters. Additionally, polar bears swimming at or near the surface would be exposed to lower sound pressure levels than indicated by the modeled or measured distances due to pressure release effects at the surface.

TABLE 4. Expected densities of pinnipeds and polar bears in the east survey area of the US Beaufort Sea in October.

	East survey area					
	<200 m		**200–1000 m**		**>1000 m**	
Species	**Average density (#/km^2)**	**Maximum density (#/km^2)**	**Average density (#/km^2)**	**Maximum density (#/km^2)**	**Average density (#/km^2)**	**Maximum density (#/km^2)**
Pinnipeds						
Ringed seal	0.0840	0.1680	0.0840	0.1680	0.0001	0.0002
Bearded seal	0.0004	0.0008	0.0004	0.0008	0.0004	0.0008
Spotted seal	0.0001	0.0002	0.0001	0.0002	0.0001	0.0002
Ribbon seal	0.0001	0.0002	0.0001	0.0002	0.0001	0.0002
Pacfic walrus	0.0001	0.0002	0.0001	0.0002	0.0001	0.0002
Ursids						
Polar bear	0.0001	0.0002	0.0001	0.0002	0.0001	0.0002

TABLE 5. Expected densities of pinnipeds and polar bears in the west survey area of the US Beaufort Sea in November–December.

	West survey area					
	<35 m		**35–200 m**		**>200 m**	
Species	**Average density (#/km^2)**	**Maximum density (#/km^2)**	**Average density (#/km^2)**	**Maximum density (#/km^2)**	**Average density (#/km^2)**	**Maximum density (#/km^2)**
Pinnipeds						
Ringed seal	1.9375	2.2167	1.0000	1.2833	0.0001	0.0002
Bearded seal	0.0004	0.0008	0.0004	0.0008	0.0004	0.0008
Spotted seal	0.0001	0.0002	0.0001	0.0002	0.0001	0.0002
Ribbon seal	0.0001	0.0002	0.0001	0.0002	0.0001	0.0002
Pacic walrus	0.0001	0.0002	0.0001	0.0002	0.0001	0.0002
Ursids						
Polar bear	0.0001	0.0002	0.0001	0.0002	0.0001	0.0002

(b) Potential Number of "Takes by Harassment"

Best and Maximum Estimates of the Number of Individuals that may be Exposed to ≥160 dB

Numbers of marine mammals that might be present and potentially disturbed are estimated below based on available data about mammal distribution and densities at different locations and times of the year as described above.

The number of individuals of each species potentially exposed to received levels ≥160 dB re 1 μPa (rms) within each portion of the survey area (east and west) and water depth category was estimated by multiplying

- the anticipated area to be ensonified to ≥160 dB re 1 μPa (rms) in each portion of the survey area (east and west) and water depth category to which that density applies, by
- the expected species density.

Some of the animals estimated to be exposed, particularly migrating bowhead whales, might show avoidance reactions before being exposed to ≥160 dB re 1 μPa (rms). Thus, these calculations actually estimate the number of individuals potentially exposed to ≥160 dB rms that would occur if there were no avoidance of the area ensonified to that level.

Estimated Area Exposed to Sounds ≥160 dB rms

The area of water potentially exposed to received levels ≥160 dB rms by the proposed operations was calculated by using a GIS to buffer the planned survey tracklines within each water depth category by the associated modeled ≥160 dB rms distances. The expected sound propagation from the airgun array was modeled by JASCO Applied Research (Zykov et al. 2010) and is expected to vary with water depth. Survey tracklines falling within the <100 m, 100–1000 m, and >1000 m water depth categories were buffered by distances of 26.7 km, 27.6 km, and 31.6 km, respectively. The total area of water that would be exposed to sound ≥160 dB rms is 189,547 km^2. A breakdown by water depth classes used in association with density estimates is presented in Table 6 and Fig. 5.

TABLE 6. Estimated area (km^2) exposed to sound ≥160 dB (rms) by survey area and water depth.

	Area ensonified (km^2)	
Water Depth (m)	**East survey area**	**West survey area**
<35	-	6505
35–100	-	31030
<100	26633	37535
100–200	2240	5733
200–1000	9014	7362
>1000	62218	38813
Total	**100104**	**89443**

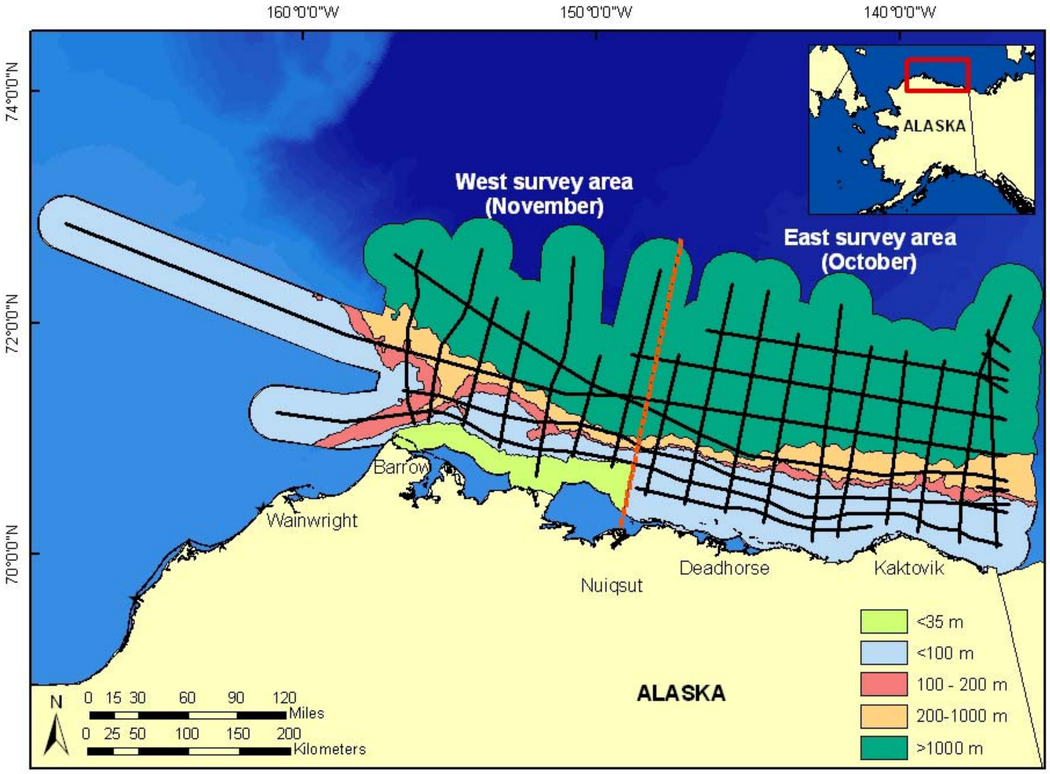


FIGURE 5. Areas estimated to be exposed to sound at received levels ≥160 dB rms by water depth category.

Based on the operational plans and marine mammal densities described above, the estimates of marine mammals potentially exposed to sounds ≥160 dB rms are presented in Tables 7, 8, and 9. For the common species, the requested numbers are calculated as described above. For less common species, estimates were set to minimal numbers to allow for chance encounters. Discussion of the number of potential exposures is summarized by species in the following subsections.

It is possible that one endangered cetacean species (bowhead whale) may be exposed to received sound levels ≥160 dB rms unless bowheads avoid the survey vessel before the received levels reach 160 dB (rms). However, the early winter timing and design of the proposed survey will minimize the number of bowheads and other cetaceans that may be exposed to seismic sounds generated by this survey. The estimates of the average number of whales potentially exposed to ≥160 dB rms are 869 and 1477 for bowheads and belugas, respectively (Table 7).

Ringed seal is the most widespread and abundant pinniped species in ice-covered arctic waters, and there is a great deal of variation in estimates of population size and distribution of these marine mammals. Ringed seals account for the vast majority of marine mammals expected to be encountered, and hence exposed to airgun sounds with received levels ≥160 dB rms during the proposed marine survey. It was estimated that ~52,559 ringed seals may be exposed to marine survey sounds with received levels ≥160 dB rms if they do not avoid the sound source. Other pinniped species are not expected to be present in the proposed survey area in large numbers in October–December, however a small number of takes of species that occur in the area during the summer months has been requested in case they are encountered (Tables 8 and 9).

TABLE 7. Estimates of the possible numbers of cetacean exposures to ≥160 dB re 1 µPa (rms) during ION's proposed seismic program in the Beaufort Sea, October–December 2010.

	<200 m		**200–1000 m**		**>1000 m**		**Total**	
Species	**Avg.**	**Max.**	**Avg.**	**Max.**	**Avg.**	**Max.**	**Avg.**	**Max.**
East survey area								
Odontocetes								
Beluga	47	188	368	1471	965	3859	1380	5518
Harbor porpoise	3	12	1	4	6	25	10	40
Mysticetes								
Bowhead whale	741	2964	7	28	6	25	754	3017
Gray whale	3	12	1	4	6	25	10	40
Minke whale	3	12	1	4	6	25	10	40
Humpback whale	3	12	1	4	6	25	10	40
West survey area								
Odontocetes								
Beluga	7	28	30	120	60	241	97	389
Harbor porpoise	4	17	1	3	4	16	9	36
Mysticetes								
Bowhead whale	111	444	1	2	4	16	115	462
Gray whale	4	17	1	3	4	16	9	36
Minke whale	4	17	1	3	4	16	9	36
Humpback whale	4	17	1	3	4	16	9	36

TABLE 8. Estimates of the possible numbers of pinniped and polar bear exposures to ≥160 dB re 1 µPa (rms) during ION's proposed seismic program in the East Beaufort Sea, October–December 2010.

Area	**East**						**Total**	
Water Depth (m)	**<200**		**200–1000**		**>1000**			
	Avg.	**Max.**	**Avg.**	**Max.**	**Avg.**	**Max.**	**Avg.**	**Max.**
Pinnipeds								
Ringed seal	2425	4851	757	1514	6	12	3189	6377
Bearded seal	12	23	4	7	25	50	40	80
Spotted seal	3	6	1	2	6	12	10	20
Ribbon seal	3	6	1	2	6	12	10	20
Pacific walrus	3	6	1	2	6	12	10	20
Ursids								
Polar bear	3	6	1	2	6	12	10	20

TABLE 9. Estimates of the possible numbers of pinniped and polar bear exposures to ≥160 dB re 1 µPa (rms) during ION's proposed seismic program in the West Beaufort Sea, October–December 2010.

Area	**West**						**Total**	
Water Depth (m)	**<35**		**35–200**		**>200**			
	Avg.	**Max.**	**Avg.**	**Max.**	**Avg.**	**Max.**	**Avg.**	**Max.**
Pinnipeds								
Ringed seal	12603	14419	36763	47179	4	8	49370	61606
Bearded seal	3	5	15	29	16	31	33	66
Spotted seal	1	1	4	7	4	8	8	16
Ribbon seal	1	1	4	7	4	8	8	16
Pacific walrus	1	1	4	7	4	8	8	16
Ursids								
Polar bear	1	1	4	7	4	8	8	16

(4) Conclusions

Cetaceans

If cetaceans are encountered during the survey they will likely show avoidance of airgun sounds at levels ≥160 dB rms. It is likely that some whales will remain in the Beaufort Sea during the survey and may be exposed to sound ≥160 dB rms. However, most whales will have migrated out of the Beaufort Sea and will not be present during the proposed survey. Furthermore, the spatial and temporal design of the proposed survey will minimize encounters with whales. While some belugas and bowhead whales may be present in the study area during the proposed seismic operations, other cetacean species, including gray whale, humpback whale, fin whale, Minke whale, and harbor porpoise are not expected to be present during October–December, however individual animals may be encountered.

Taking into account the mitigation measures that are planned, effects on cetaceans are generally expected to be restricted to avoidance of a limited area around the survey operation and short-term changes in behavior, falling within the MMPA definition of "Level B harassment". The estimated numbers of animals potentially exposed to sound levels sufficient to cause appreciable disturbance are relatively small percentages of the population sizes in the Bearing–Chukchi–Beaufort seas, as described below.

For species listed as endangered under the ESA, the only species likely to be in the area during operations and exposed to received levels ≥160 dB rms is the bowhead whale, and it is estimated that 869 bowheads may be exposed at this level. This represents ~6% of the Bering–Chukchi–Beaufort population of bowhead whales that is estimated to be >14,247 in 2010 assuming 3.4% annual population growth from the 2001 estimate of >10,545 animals (Zeh and Punt 2005).

The only other cetacean species likely to be present in the study area is the beluga, and it is estimated that 1477 belugas may be exposed to sound at received levels ≥160 dB rms. This represents ~4% of the Beaufort Sea population (Angliss and Allen 2009).

The many reported 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 controlled vessel speed, dedicated marine mammal observers, non-pursuit, shut downs or power downs when marine mammals are seen within defined ranges will 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. Subsistence issues are addressed below in section VIII.

Pinnipeds

Ringed seal is the only pinniped species likely to be present in the survey area in significant numbers. The best estimate of the numbers of individual seals exposed to airgun sounds at received levels ≥160 dB rms during the survey is 52,559 ringed seals. However, this estimate does not take into consideration the fact that some proportion of those seals will be hauled out on ice and therefore not exposed to seismic sounds at received levels ≥160 dB rms. It is also possible that relatively small numbers of bearded, spotted, and ribbon seals and Pacific walrus may be taken by harassment as a result of the proposed survey. It is estimated that 76 bearded seals, 19 spotted and ribbon seal, and 19 Pacific walruses may be exposed to seismic sounds at received levels ≥160 dB rms, however this represents less than 1-2% of these populations (Angliss and Allen 2009). The short-term exposures of seals to airgun sounds are not expected to result in any long-term negative consequences for the individuals or their populations.

Polar Bear

Encounters with polar bears are unlikely in offshore areas with open water or thin, newly forming ice. Any individuals encountered that are in the water near the operating seismic equipment would be exposed to lower sound pressure levels than indicated by the safety and disturbance radii due to pressure release effects at the surface. Encounters are more likely to occur in locations with thicker first year ice, or multi-year ice, that can support the weight of the animals. However, polar bears on ice would not be exposed to underwater seismic sounds and effects would be limited to reactions to the vessels themselves.

(5) Direct Effects on Fish, EFH, and Fisheries, and Their Significance

(a) Effects on Fish and Invertebrates

One of the reasons for the adoption of airguns as the standard energy source for marine seismic surveys was that, unlike explosives, they do not result in any appreciable fish kill. However, the existing body of information relating to the impacts of seismic on marine fish and invertebrate species is very limited. A detailed review of the effects of airgun sounds on fish is presented in Appendix D.

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 (Hubbs and Rechnitzer 1952 *in* Wardle et al. 2001). 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 pathological zone for fish and invertebrates would be expected to be within a few meters of the seismic source (Buchanan et al. 2004). For the proposed survey, any injurious effects on fish would be limited to very short distances.

The proposed seismic program in the Beaufort and Chukchi seas in 2010 is predicted to have negligible to low physical effects on the various life stages of fish and invertebrates. Therefore, physical effects of the proposed program on fish and invertebrates would be not significant.

(b) EFH

A very small proportion of the proposed survey off northern Alaska may be conducted in an area technically designated as Essential Fish Habitat (EFH) by virtue of the fact that adult salmon may use those waters (NPFMC 2009). Small numbers of salmon could occur in the proposed survey area and would likely be most abundant in the southern portion. Effects on managed EFH species (salmon) by the seismic operations assessed here would be temporary and minor (see above). Fish would have to be very close to the sound source (perhaps within a few meters) to be affected by sound pulses. The main effect would be short-term disturbance that might lead to temporary and localized relocation of the EFH species or their food. The actual physical and chemical properties of the EFH will not be impacted.

(c) Fisheries

No active fishing is expected to be conducted within the study area during the time of the survey. Any on-going fisheries near the project area would be subsistence, and much closer to shore than the actual survey.

(6) 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 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 nearby seismic survey activities. Seismic activity also did not appear to change the diving intensity of long-tailed ducks significantly. The predominant airgun source involved in the study by Lacroix et al. 2003 (Lawson 2002) was smaller in total volume than that planned for the proposed survey. In addition, much of the seismic activity during the Lacroix et al. (2003) study occurred within or just outside of barrier islands and much closer to shore than most of ION's proposed seismic survey.

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 on island colonies—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. This is not applicable to the proposed survey, which will be in offshore waters away from any seabird colonies. Additionally, the timing of the proposed survey in October/December will be well after the seabird nesting period has been completed.

Egg and nestling mortality—Disturbance of adult birds from nests can lead to egg or nestling mortality *via* temperature stress or predation. There is no potential for this considering the distance that the seismic survey will occur from nesting colonies, and the timing of the survey after completing of the nesting period.

Chance injury or mortality—Many species of marine birds feed by diving to depths of several meters or more. Flocks of feeding birds consisting of hundreds or thousands of birds often occur in Alaskan waters. Also, some species of seabirds (particularly alcids) escape from boats by diving when the boat is 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 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—By disorienting, injuring, or killing prey species, or by otherwise increasing the availability of prey species to marine birds, seismic activity could attract birds. Birds drawn too close to an airgun may be at risk of injury. However, available evidence from other seismic surveys has not shown a pattern of fish (or other prey) kills from airguns [see § IV(5)(a), above]. Thus, the potential that birds would be attracted and subsequently injured by the proposed seismic survey appears very low.

(5) Indirect Effects to Marine Mammals and Their Significance

The proposed airgun operations will not result in any permanent impact on habitats used by marine mammals, or to the food sources they use. The main impact issue associated with the proposed activities will be temporarily elevated noise levels and the associated direct effects on marine mammals, as discussed above, as well as the potential effects of icebreaking, including locally altered ice conditions and the potential for the destruction of ringed seal lairs or polar bear dens.

Icebreaking will open leads in the sea ice along the vessel tracklines and could potentially destroy ringed seal lairs or polar bear dens. Ringed seals hollow out lairs in the snow that accumulates on the sea ice near their breathing holes. It would be impossible for a marine mammal observer to detect these lairs with the unaided eye or binoculars in order to avoid their destruction. However, use of a forward-looking thermal imaging (FLIR) system may be useful for this type of mitigation if a lair is occupied, depending on the range at which it is first detected. Damage to lairs caused by survey activities is not expected to exceed that which occurs naturally, and lair destruction in the early winter would likely not impact ringed seal survival. Lanugal pups born in the spring can become hypothermic if wetted, but by early winter they are robust to submersion (Smith et al. 1991). The highest density of ringed seals reported from aerial surveys conducted during spring when seals were emerging from their dens was in areas of water depth 5–35 m (Frost et al. 2004). Approximately 385 km (7%) of the proposed survey trackline is planned in that area.

Polar bears typically den on shore in October–November (Lentfer and Hensel 1980), and although most maternal denning appears to occur on the mainland and islands, Amstrup and Gardner (1994) discovered that 53% of the dens of polar bears radio-collared between 1981 and 1991were on drifting pack ice, and 4% were on landfast ice adjacent to shore. Polar bears den in a diffuse pattern and individual dens are scattered over broad reaches of habitat at low density (Lentfer and Hensel 1980; Amstrup and Gardner 1994), so the number of dens that would potentially be destroyed by icebreaking activities is estimated to be low. Polar bears seem more resilient to the loss of a den during fall and early winter than after parturition, probably due to the increased vulnerability of cubs during spring (Amstrup 1993).

During the seismic survey only a small fraction of the available habitat would be ensonified at any given time. Disturbance to fish species would be short-term and fish would return to their pre-disturbance behavior once the seismic activity ceases. Thus, the proposed survey would have little, if any, impact on the abilities of marine mammals to feed in the area where seismic work is planned.

Some mysticetes, including bowhead whales, feed on concentrations of zooplankton. Some feeding bowhead whales may occur in the Alaskan Beaufort Sea in July and August, and others feed intermittently during their westward migration in September and October (Richardson and Thomson [eds.] 2002; Lowry et al. 2004; Lyons et al. 2009; Christie et al. 2009). 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 feeding mysticetes. In addition, seismic work is planned during a period when few bowheads and other whale species are likely to be present or feeding in the area.

(6) Possible Effects on Subsistence Hunting

Subsistence hunting and fishing continue to be prominent in the household economies and social welfare of some Alaskan residents, particularly among those living in small, rural villages (Wolfe and Walker 1987). Subsistence remains the basis for Alaska Native culture and community. In rural Alaska, subsistence activities are often central to many aspects of human existence, including patterns of family life, artistic expression, and community religious and celebratory activities.

(a) Subsistence Hunting for Marine Mammals

Marine mammals are legally hunted along the north coast of Alaska near Barrow, Nuiqsut, and Kaktovik by coastal Alaska Natives (Fig. 6). Species hunted include bowhead whales, beluga whales, ringed, spotted, and bearded seals, walrus, and polar bears. In the Barrow area, bowhead whales provided ~69% of the total weight of marine mammals harvested from April 1987 to March 1990. During that time, ringed seals were harvested the most on a numerical basis (394 animals).

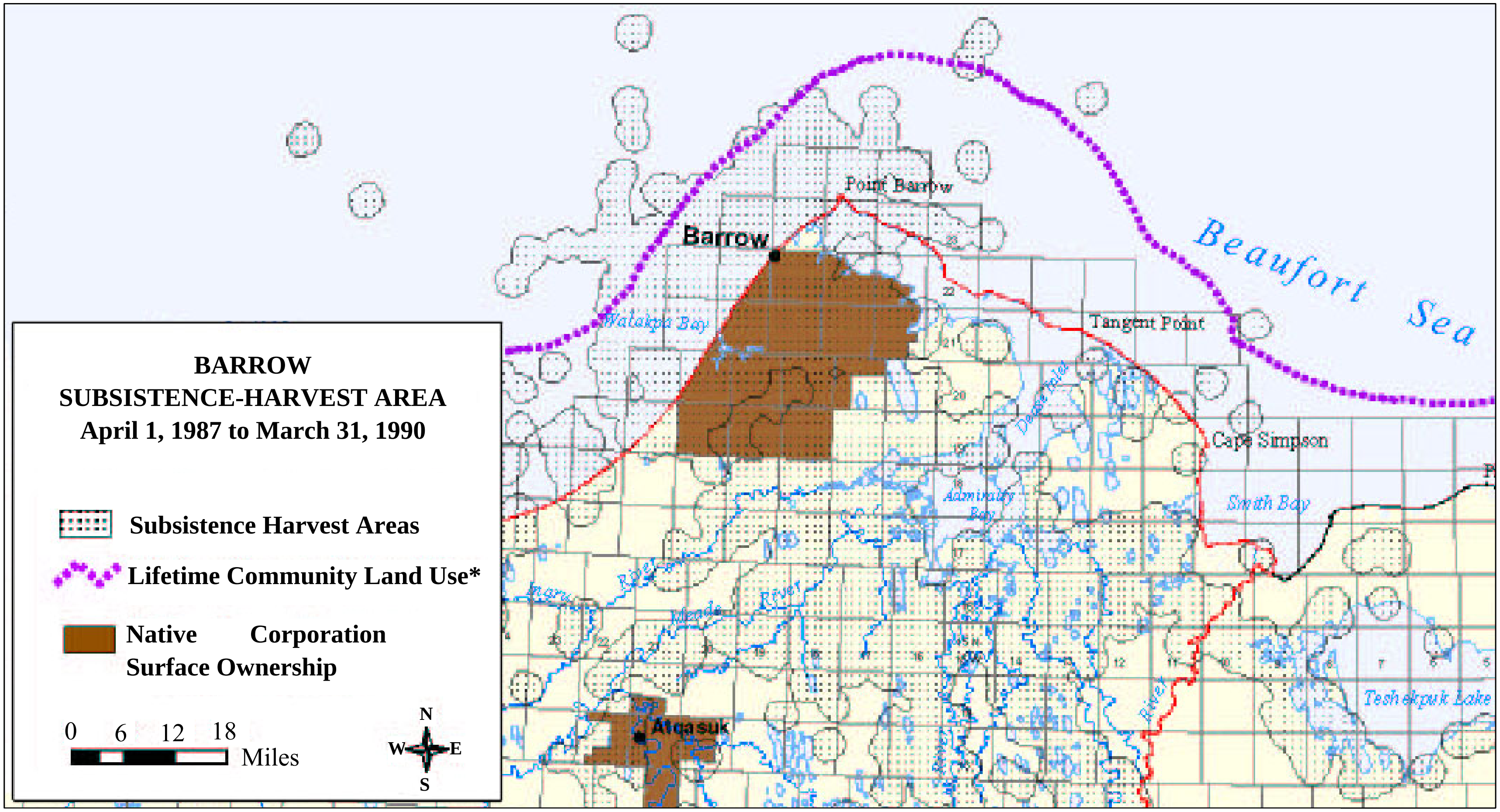
Bowhead whale hunting is the key activity in the subsistence economies of Barrow and two smaller communities to the east, Nuiqsut and Kaktovik. Whale harvests have a great influence on social relations by strengthening the sense of Inupiat culture and heritage in addition to reinforcing family and community ties.

An overall quota system for the hunting of bowhead whales was established by the International Whaling Commission in 1977. The quota is now regulated through an agreement between NMFS and the Alaska Eskimo Whaling Commission (AEWC). The AEWC allots the number of bowhead whales that each whaling community may harvest annually during five-year periods (USDI/BLM 2005). The NMFS recently proposed continuation of the bowhead hunt for the five-year period 2008-2012 (NMFS 2008b).

The community of Barrow hunts bowhead whales in both the spring and fall during the whales' seasonal migrations along the coast. Often, the bulk of the Barrow bowhead harvest is taken during the spring hunt. However, with larger quotas in recent years, it is common for a substantial fraction of the annual Barrow quota to remain available for the fall hunt (Table 10). The communities of Nuiqsut and Kaktovik participate only in the fall bowhead harvest. The fall migration of bowhead whales that summer in the eastern Beaufort Sea typically begins in late August or September. Fall migration into Alaskan waters is primarily during September and October. However, in recent years a small number of bowheads have been seen or heard offshore from the Prudhoe Bay region during the last week of August (Treacy 1993; LGL and Greeneridge 1996; Greene 1997; Greene et al. 1999; Blackwell et al. 2004).

The spring hunt at Barrow occurs after leads open due to the deterioration of pack ice; the spring hunt typically occurs from early April until the first week of June. The location of the fall subsistence hunt depends on ice conditions and (in some years) industrial activities that influence the bowheads movements as they move west (Brower 1996). In the fall, subsistence hunters use aluminum or fiberglass boats with outboards. Hunters prefer to take bowheads close to shore to avoid a long tow during which the meat can spoil, but Braund and Moorehead (1995) report that crews may (rarely) pursue whales as far as 80 km. The autumn hunt at Barrow usually begins in mid-September, and mainly occurs in the waters east and northeast of Point Barrow. The whales have usually left the Beaufort Sea by late October (Treacy 2002a,b).

The scheduling of this seismic survey has been discussed with representatives of those concerned with the subsistence bowhead hunt, most notably the Alaska Eskimo Whaling Commission (AEWC), the Barrow Whaling Captains' Association, and the North Slope Borough (NSB) Department of Wildlife Management. The timing of the proposed geophysical survey (October-December) will not affect the spring bowhead hunt. The fall bowhead hunt may still be ongoing near Barrow during October, and operations will be coordinated with the AEWC. ION may elect to operate at the eastern end of the survey area until fall whaling in the Beaufort Sea near Barrow is finished.



* The lifetime use line represents the areas used by 20 hunters over their lifetimes up to 1979 (Pederson 1979 *in* Braund et al. 1993).
Source: Map 72. USDI/BLM 2003

FIGURE 6. Barrow subsistence harvest areas, April 1987 to March 1990, indicating the extent offshore where subsistence hunting is conducted. Source: Map 72, USDI/BLM (2003).

Table 10. Number of bowhead whale landing by year at Barrow, Cross Island (Nuiqsut), and Kaktovik, 1993-2008. Barrow numbers include the total number of whales landed for the year followed by the numbers landed during the fall hunt in parenthesis.

Year	Barrow	Cross Island	Kaktovik
1993	23 (7)	3	3
1994	16 (1)	0	3
1995	19 (11)	4	4
1996	24 (19)	2	1
1997	30 (21)	3	4
1998	25 (16)	4	3
1999	24 (6)	3	3
2000	18 (13)	4	3
2001	27 (7)	3	4
2002	22 (17)	4	3
2003	16 (6)	4	3
2004	21 (14)	3	3
2005	29 (13)	1	3
2006	22 (19)	4	3
2007	20 (7)	3	3
2008	21(12)	4	3

1 Compiled in USDI/BLM (2003) from various sources.

2 Numbers given for Barrow are “total landings/autumn landings”. From Burns et al. (1993), various issues of Report of the International Whaling Commission, Alaska Eskimo Whaling Commission, J.C. George (NSB Dep. Wildl. Manage.), Suydam et al. 2004, 2005b, 2006, 2007, 2008, 2009.

3 Cross Isl. (Nuiqsut) and Kaktovik landings are in autumn. Data compiled in Koski et al. (2005) from various sources.

Beluga whales are available to subsistence hunters at Barrow in the spring when pack-ice conditions deteriorate and leads open up. Belugas may remain in the area through June and sometimes into July and August in ice-free waters. Hunters usually wait until after the spring bowhead whale hunt is finished before turning their attention to hunting belugas. The average annual harvest of beluga whales taken by Barrow for 1962–1982 was five (MMS 1996). The Alaska Beluga Whale Committee recorded that 23 beluga whales had been harvested by Barrow hunters from 1987 to 2002, ranging from 0 in 1987, 1988 and 1995 to the high of 8 in 1997 (Fuller and George 1999, Alaska Beluga Whale Committee 2002 *in* USDI/BLM 2005). During 2003-2005, the average annual beluga whale harvest for Barrow was 3 (Appendix C *in* MMS 2007). The timing of the proposed survey will not overlap with the beluga harvest.

Ringed seals are hunted near Barrow mainly from October through June. Winter leads in the area off Pt. Barrow and along the barrier islands of Elson Lagoon to the east are used for hunting ringed seals. The average annual ringed seal harvest by the community of Barrow from the 1960s through much of the 1980s has been estimated as 394 (Braund et al. 1993). More recently Bacon et al. (2009) estimated that 586, 287, and 413 ringed seals were harvested by villagers at Barrow in 2000, 2001, and 2003, respectively. Ringed seals are also harvested by Nuiqsut hunters off the Colville River Delta in Harrison Bay, between Fish Creek and Pingok Island, which is south of the project area. Seal hunting occurring in this area before spring break-up is by snow machine and by boat during summer. In 1992, Nuiqsut hunters harvested 22 of 24 (92%) ringed seals during the open water season from July to October (Fuller and George 1997). Harvest data for 1994 and 1995 show 17 of 23 (74%) ringed seals were taken from June to August (Brower and Opie 1997). The seismic survey will largely be in offshore waters where the activities will not influence ringed seals in the nearshore areas where they are hunted.

The ***spotted seal*** subsistence hunt peaks in July and August, at least in 1987 to 1990, but involves few animals. Spotted seals typically migrate south by October to overwinter in the Bering Sea, and therefore the proposed October–December survey will not affect hunting of this species. Admiralty Bay, <60 km to the east of Barrow, is a location where spotted seals are harvested. Spotted seals are also occasionally hunted in the area off Point Barrow and along the barrier islands of Elson Lagoon to the east (USDI/BLM 2005). The average annual spotted seal harvest by the community of Barrow from 1987-1990 was one (Braund et al. 1993). More recently however, Bacon et al. (2009) estimated that 32, 7, and 12 spotted seals were harvested by villagers at Barrow in 2000, 2001, and 2003, respectively. Spotted seals become less abundant at Nuiqsut and Kaktovik and few if any spotted seal are harvested at these villages.

Bearded seals, although not favored for their meat, are important to subsistence activities in Barrow because of their skins. Six to nine bearded seal hides are used by whalers to cover each of the skin-covered boats traditionally used for spring whaling. Because of their valuable hides and large size, bearded seals are specifically sought. Bearded seals are harvested during the summer months in the Beaufort Sea (USDI/BLM 2005). The animals inhabit the environment around the ice floes in the drifting ice pack, so hunting usually occurs from boats in the drift ice. Braund et al. (1993) estimated that 174 bearded seals were harvested annually at Barrow from 1987-1990. More recently Bacon et al. (2009) estimated that 728, 327, and 776 bearded seals were harvested by villagers at Barrow in 2000, 2001, and 2003, respectively. Braund et al. (1993) mapped the majority of bearded seal harvest sites from 1987 to 1990 as being within ~24 km of Point Barrow. In 1992, Nuiqsut hunters harvested 16 bearded seals during the open water season from July to October (Fuller and George 1997). However, there was no record of bearded seals being harvested in 1994 and 1995 (Brower and Opie 1997). Because bearded seal hunting typically occurs during the summer months, the proposed survey is not expected to affect bearded seal harvests.

The USFWS has monitored the harvest of ***polar bears*** in Alaska using a mandatory marking, tagging, and reporting program implemented in 1988. Polar bears are harvested in the winter and spring, but comprise a small percent of the annual subsistence harvest. Braund et al. (1993) reported that ~2% of the total edible pounds harvested by Barrow residents from 1987 to 1989 involved polar bears. The USFWS estimated that from 1996 to 2000 the average annual harvest of polar bears in Alaska was ~45 animals (Angliss and Allen 2009). Bacon et al. (2009) estimated that 11, 5, and 21 polar bears were harvested by villagers from Barrow in 2000, 2001, and 2003, respectively. Fewer polar bears were harvested by villagers at Nuiqsut and Kaktovik. In 2004/2005, the harvest in Alaska was 27 bears (Schliebe et al. 2006, NSB-IGC Report) which included harvests at other smaller communities besides Barrow. It is not expected that the offshore seismic survey will interfere with polar bear subsistence hunting.

Walruses are hunted primarily from June through mid-August to the west of Point Barrow and southwest to Peard Bay. Walruses rarely occur in the Beaufort Sea north and east of Barrow and become less abundant further east. The harvest effort peaks in July. The annual walrus harvest by Barrow residents ranged from 7 to 206 animals from 1990 to 2002 (Fuller and George 1999; Schliebe 2002 *in* USDI/BLM 2005). During 2003-2005, the average annual walrus harvest for Barrow was 36, ranging from 5 in 2005 to the high of 52 in 2004 (Appendix C *in* MMS 2007). Because walrus hunting typically occurs during summer months, the proposed survey is not expected to affect walrus harvests.

In the event that both marine mammals and hunters were near the *Geo Explorer* when it is conducting operations near Barrow, the proposed project potentially could impact the availability of marine mammals for the harvest in a very small area immediately around the *Geo Explorer*.

(b) Consultation with Local Barrow Community

ION has worked with the people of Barrow to identify and avoid areas of potential conflict. A representative of the project met with the NSB and AEWC on December 15, 2009 in Barrow. Additional meetings and/or presentations to community groups are currently being organized. Also, ION plans to participate in the "open water peer/stakeholder review meeting" to be convened by NMFS in Anchorage in March 2010, where representatives of the AEWC and NSB are also expected to participate.

At least one Alaska Native knowledgeable about the marine mammals of the area is expected to be included as a member of the MMO team. The primary duty of this individual will be as a member of the MMO team responsible for implementing the monitoring and mitigation requirements. However, the Alaska Native MMO will also be the "Inupiat Communicator". The Communicator will provide for liaison with hunters if they are encountered at sea, and with the Whaler Communication Center that is expected to be in operation, at least during October. However, due to the timing of the proposed activity, encounters with subsistence hunters at sea are unlikely, and are not expected to affect the success of subsistence hunters.

(7) Cumulative Effects

Cumulative effects refer to the impacts on the environment that result from a combination of past, existing, and imminent projects and human activities. 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 Alaskan Beaufort and Chukchi seas include whaling and sealing, commercial fishing, oil and gas development, and vessel traffic. These activities, when conducted separately or in combination with other activities, can affect marine mammals in the proposed survey area. Any cumulative effects caused by the addition of the seismic survey impacts on marine mammals will be extremely limited, especially considering the timeframe of the proposed activities.

(a) Commercial Fishing

Commercial fisheries in the Alaskan Beaufort Sea are very limited. The Helmericks family operates an under-ice commercial gill net fishery during fall in the Colville River Delta (Gallaway et al. 1983, 1989). The fishery typically operates from early October through the end of November. Fishing effort is concentrated in the Main (Kupigruak) and East Channels of the river near Anachilik Island. The three principal species targeted in the fishery are arctic cisco, least cisco, and humpback whitefish.

The proposed survey will have a negligible impact on the marine mammals in the study area. The combination of ION's activities with those of fisheries will not result in any detectable increment in impacts on marine mammals over and above the impacts from the fisheries alone.

(b) Oil and Gas Development

Oil and gas development in the Alaskan Beaufort Sea and on the Arctic Coastal Plain has been considerable. USDI/MMS (2003) listed 17 offshore North Slope oil and gas discoveries and 46 onshore discoveries as of 1 July 2002.

Recent oil field developments include Alpine (onshore), which came on line in November 2000 and now produces over 100,000 barrels of oil per day; Northstar (offshore), which began production October 2001 and is currently producing ~22,477 barrels of oil per day; and the Pioneer Natural Resources development at Oooguruk Drill Site in eastern Harrison Bay which began production in 2008. The Northstar production facility is the only one currently operating in the Beaufort Sea north (seaward) of the barrier islands. The offshore (but in a lagoon) Endicott field began production in 1987 and had produced 439 million barrels of oil through Feb 1995 (AOGCC 2005). The Niakuk, Pt. McIntyre, and Badami fields are located offshore, but production facilities are located onshore. The Alpine oil field is the westernmost of the oil field developments and is ~ 241 km southeast of Barrow. Two other developments which may come into production within the next several years include the BP Liberty development and the Eni Spy Island development.

The existing oil fields are serviced by land, air, and sea. Marine activities associated with the on-land oil developments in northern Alaska consist mainly of tug and barge traffic, mainly in nearshore waters along the north coast. Vessel traffic including barges and crew boats to Northstar Island have been ongoing during the open-water season, although much of the crew vessel traffic has been largely replaced by hovercraft and helicopter traffic, neither of which introduces much noise into the sea (Blackwell and Greene 2005). During the last several years barges and crew vessels have been used in support of activities at Pioneer's Oooruruk site, and in support of island construction by Eni at their Spy Island Drillsite located inside Spy Island in eastern Harrison Bay. Several supply vessels travel along the Beaufort Sea coast, transporting fuel and construction materials to communities and industrial centers. Two or three supply vessels routinely travel between Barrow and Kaktovik during the summer, with two additional vessels operating out of Prudhoe Bay.

Open-water industry seismic surveys were conducted in the Alaskan Chukchi and Beaufort seas each year since 2006 during the open-water season. BP and Eni also had smaller ocean bottom cable seismic survey programs in the general Prudhoe Bay area in 2008. Other seismic survey programs were conducted in the southern Alaskan Beaufort Sea from 1996–2001 (Richardson and Lawson 2002). These surveys occurred much closer to shore than the proposed ION survey and may be ongoing in 2010. The timing of the potential industry surveys in 2010 is not precisely known but most activity would occur prior to the proposed ION activities.

In addition to the potential for continued industry seismic exploration, offshore exploratory drilling may also occur in 2010 in the southern Beaufort Sea and the Chukchi Sea. Exploratory drilling activities in the Beaufort Sea would occur in nearshore locations could extend into October and overlap with the initial ION activities.

Noise generated by oil industry activities in the nearshore zone, such as Northstar, generally is not detectable underwater more than a few km from facilities although vessel sound may be audible at greater distances (Blackwell and Greene 2006). Underwater sounds from vessels supporting oil industry activities are often detectable farther away. Most industry-related vessel activities are generally terminated in October and may occur simultaneously with the initial ION's initial survey activities.

(c) Vessel Traffic

In heavily-traveled areas, shipping noise generally dominates ambient noise at frequencies from 20 to 300 Hz, although that is not the case in most of the Arctic (Richardson et al. 1995a). Baleen whales are thought to be more sensitive to sound at those low frequencies than are toothed whales. Other than the *Geo Explorer* and the *Vladimir Ignatyuk*, no other vessels are likely to be operating in and near the proposed seismic survey area in October–December. Bowhead whales, in particular, often move away when vessels approach within several kilometers (Richardson and Malme 1993), and hunters at Barrow believe that vessel traffic near the coast southeast of Barrow can cause larger-scale displacement of bowheads. However, the majority of migrating bowheads are expected to have left the proposed study area by the time both survey vessels arrive.

Responses of belugas to vessel traffic are highly variable (Richardson et al. 1995a), and can extend to tens of kilometers in special circumstances (Finley et al. 1990). Belugas may also be tolerant of large vessels traveling in consistent directions but may flee from fast erratic movements from smaller boats (Richardson et al. 1995a).

Aside from vessels supporting the oil industry (discussed in preceding subsection), vessel traffic in the proposed study area is limited. The majority of the other vessels will be within 20 km of the coast, and will include Native vessels used for fishing and hunting, cruise ships, icebreakers, Coast Guard vessels, and supply ships. Several supply vessels are also scheduled to visit the North Slope communities from Barrow to Kaktovik, and some traffic may continue on to Canada delivering fuel and construction equipment. An unknown number of trips by U.S. and Canadian Coast Guard vessels are also likely. Most of this vessel traffic will occur prior to the start of the proposed geophysical survey.

The addition of the proposed survey activities will not augment the impacts to marine mammals that occur due to routine vessel traffic in the area of the survey.

(d) Oil Spills

There is always the risk of an oil spill in the study area. However, the *Geo Explorer* and *Vladimir Ignatyuk* are certified, maintained and operated to high standards. It is highly unlikely that the *Geo Explorer* or *Vladimir Ignatyuk* will be the source of an oil spill of any significant impact. The *Geo Explorer* and *Vladimir Ignatyuk's* fuel capacity is relatively trivial when compared to the amount of oil produced from the offshore fields in the Beaufort Sea.

(e) Hunting

Marine mammals are legally hunted in Alaskan waters by coastal Alaska Natives. In the Alaskan Beaufort and Chukchi seas, bowhead whales, beluga whales, Pacific walruses, ringed, spotted, and bearded seals, and polar bears are hunted (see Section IV[***6***]). The hunting communities within the area of the proposed survey are Barrow, Nuiqsut (Cross Island), and Kaktovik in the Alaskan Beaufort Sea. The planned project (unlike subsistence hunting activities) will not result in directed or lethal takes of marine mammals. Also, the direct disturbance-related impacts of the project on individuals are anticipated to be short-term and inconsequential to the long-term well being of those individuals and their populations. Thus, the combined effects of the project and of subsistence hunting on marine mammal stocks are not expected to differ appreciably from those of subsistence hunting alone.

(f) Summary of Cumulative Impacts

For the majority of the proposed trackline, the *Geo Explorer* and *Vladimir Ignatyuk* are unlikely to encounter any additional human activities, and thus the degree of cumulative impact will be minimal. Any such effects related to the cumulation of human activities near the start and end of the trackline will have no more than a negligible impact on the marine mammal populations encountered.

(8) Unavoidable Impacts of Noise

Unavoidable impacts to marine mammals occurring in the proposed study area in the Beaufort Sea will be limited to short-term changes in behavior and local distribution. For cetaceans and pinnipeds, 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 individual marine mammals, or on the populations to which they belong. Effects on recruitment or survival are expected to be (at most) negligible. Also, any effects on accessibility of marine mammals for subsistence hunting and effects on commercial fishing are expected to be (at most) negligible.

(9) Coordination with Other Agencies and Processes

This EA has been prepared for and adopted by ION primarily to address issues relating to the request that an IHA be issued by NMFS to authorize "taking by harassment" (disturbance) of small numbers of cetaceans and pinnipeds during ION's planned seismic survey. Another important component has been to address potential impacts on polar bears and walruses, which are managed by USFWS.

ION will coordinate the planned marine mammal monitoring program associated with the seismic survey in the Beaufort Sea with other parties that may have interest in this area and/or be conducting marine mammal studies in the same region during operations. No other marine mammal studies are expected to occur in the survey area at the proposed time. However, other industry-funded seismic surveys may be occurring in the northeast Chukchi and/or western Beaufort Sea earlier than the proposed ION survey, and those projects are likely to involve marine mammal monitoring. Further coordination of monitoring programs can occur during and after the planned Beaufort open-water peer review meeting in Anchorage in spring 2010.

ION has and will continue to coordinate, with other applicable Federal, State and Borough agencies, and will comply with their requirements. Actions of this type that are underway in parallel with the ongoing request to NMFS for issuance of an IHA include the following:

- LGL has had contact with USFWS biologists of the Office of Marine Mammal Management, Anchorage, on ION's behalf regarding potential interactions with polar bears and walruses.
- ION will coordinate with the NSB Department of Wildlife Management biologists, Craig George and Robert Suydam, concerning marine mammal issues.
- ION will coordinate with representatives of subsistence hunters in Barrow with regard to potential concerns about interactions with subsistence hunting and negotiation of a "Plan of Cooperation", if required.

Alternative Action: Another Time

The seismic portion of the proposed survey will be conducted for ~76 days from about 1 October to 15 December 2010. An alternative to issuing the IHA for the period requested, and to conducting the project within that period, is to issue the IHA for another period, and to conduct the project during that alternative period. However, conducting the project at some other time of year would likely result in more marine mammals being exposed to airgun sounds. In addition, the proposed period for the cruise is the period when the ship and all of the personnel and equipment essential to meet the overall project objectives are available. Postponing or changing the project period will delay this and potentially other scheduled projects during the rest of 2010.

One of the most effective measures to minimize impacts on marine mammals from seismic activity is to perform these activities during a period when few marine mammal species are expected to be present. Bowhead, beluga whales and walruses are migratory, moving through the area of the survey in the spring and then again in the fall (see Section III, above). The cruise has been timed to avoid the bowhead and beluga migrations. Moving the ION seismic survey early into the open-water period would result in operations being closer to (or into) the main migration periods for those whale species. Ringed seals, the most abundant marine mammal in the area of the survey, and polar bears are year-round residents in Alaska (see Section III, above), so altering the timing of the proposed project likely would result in no net benefits for those species. For other marine mammal species there are insufficient data to predict when their abundance may be highest.

Subsistence harvests of ringed seals, bearded seals and bowhead whales occur near Barrow, Nuiqsut and Kaktovik. Marine mammal harvests take place year-round, but subsistence harvest peaks during the bowhead whale hunts in the spring and fall. The harvest is of great value to the Inupiat people, both culturally and as a food source. The survey has been scheduled to avoid the subsistence harvest of bowheads.

No Action Alternative

An alternative to conducting the proposed activities is the "No Action" alternative, i.e. the geophysical survey is not conducted and no IHA is issued. If the research were not conducted, the "No Action" alternative would result in no disturbance to marine mammals attributable to the proposed seismic activities. However, there would be little reduction in impacts if the project did not go ahead, given the negligible effects on marine mammals, seabirds, fish, subsistence hunting, and fisheries that are anticipated if the project goes ahead as planned.

V. LIST OF PREPARERS

LGL Alaska Research Associates Inc. and **LGL Ltd., environmental research associates**

Joseph Beland, M.M.M., Anchorage, AK *
Danielle Savarese, M.Sc., Anchorage, AK*
Darren Ireland, M.Sc., Anchorage, AK*
William R. Koski, M.Sc., King City, Ont.
Michelle Gilders, M.Sc., Sidney, B.C.
William Cross, M.Sc., King City, Ont.
Meike Holst, M.Sc., Sidney, B.C.
W. John Richardson, Ph.D., King City, Ont.

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

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APPENDIX A

MARINE FISH OF THE BEAUFORT SEA AND ARCTIC OCEAN. FROM FISHBASE.ORG

Species	Name	Family	Habitat	Length (cm)	Trophic Level	Status
Aspidophoroides bartoni	Aleutian alligatorfish	Agonidae	demersal	22.0 TL	3.3	native
Leptagonus decagonus	Atlantic poacher	Agonidae	demersal	21.0 TL	3.2	native
Occella dodecaedron	Bering poacher	Agonidae	demersal	26.4 TL	3.2	native
Podothecus accipenserinus	Sturgeon poacher	Agonidae	demersal	30.5 TL	3.4	native
Ulcina olrikii	Arctic alligatorfish	Agonidae	demersal	8.6 TL	3.3	native
Ammodytes dubius	Northern sand lance	Ammodytidae	demersal	25.0 TL	3.1	native
Ammodytes hexapterus	Pacific sand lance	Ammodytidae	benthopelagic	30.0 TL	3.1	native
Anarhichas denticulatus	Northern wolffish	Anarhichadidae	benthopelagic	180.0 TL	3.8	native
Anarrhichthys ocellatus	Wolf-eel	Anarhichadidae	demersal	240.0 TL	3.5	native
Bathymaster signatus	Searcher	Bathymasteridae	demersal	38.0 TL	3.5	native
Clupea pallasii pallasii	Pacific herring	Clupeidae	pelagic-neritic	46.0 TL	3.2	native
Artediellus scaber	Hamecon	Cottidae	demersal	8.4 TL	3.3	native
Artediellus uncinatus	Arctic hookear sculpin	Cottidae	demersal	10.0 TL	3.5	native
Gymnocanthus pistilliger	Threaded sculpin	Cottidae	demersal	28.0 TL	3.1	native
Gymnocanthus tricuspis	Arctic staghorn sculpin	Cottidae	demersal	30.0 TL	3.5	native
Hemilepidotus papilio	Butterfly sculpin	Cottidae	demersal	36.6 TL	3.3	native
Hemilepidotus zapus	Longfin Irish lord	Cottidae	demersal	26.0 TL	3.4	native

Species	Name	Family	Habitat	Length (cm)	Trophic Level	Status
Icelus bicornis	Twohorn sculpin	Cottidae	demersal	19.1 TL	3.1	native
Icelus spatula	Spatulate sculpin	Cottidae	demersal	21.0 TL	3.9	native
Megalocottus platycephalus platycephalus	Belligerent sculpin	Cottidae	demersal	42.0 TL	4.1	native
Myoxocephalus jaok	Plain sculpin	Cottidae	demersal	74.0 TL	4.2	native
Myoxocephalus scorpioides	Arctic sculpin	Cottidae	demersal	22.0 TL	3.4	questionable
Myoxocephalus scorpius	Shorthorn sculpin	Cottidae	demersal	60.0 TL	3.9	native
Myoxocephalus stelleri	Steller's sculpin	Cottidae	reef-associated	60.0 TL	3.9	native
Myoxocephalus verrucosus	Warty sculpin	Cottidae	demersal	30.0 TL	3.7	native
Triglops nybelini	Bigeye sculpin	Cottidae	demersal	24.9 TL	3.3	native
Triglops pingelii	Ribbed sculpin	Cottidae	demersal	24.6 TL	3.4	native
Triglopsis quadricornis	Fourhorn sculpin	Cottidae	demersal	60.0 TL	3.7	native
Cyclopteropsis jordani	Smooth lumpfish	Cyclopteridae	demersal	7.4 TL	3.4	native
Eumicrotremus andriashevi	Pimpled lumpsucker	Cyclopteridae	demersal	5.9 TL	3.2	native
Eumicrotremus derjugini	Leatherfin lumpsucker	Cyclopteridae	demersal	12.2 TL	3.3	native
Eumicrotremus orbis	Pacific spiny lumpsucker	Cyclopteridae	demersal	18.0 TL	3.2	native
Eumicrotremus spinosus	Atlantic spiny lumpsucker	Cyclopteridae	demersal	12.2 TL	3.5	native
Arctogadus borisovi	East Siberian cod	Gadidae	demersal	55.6 TL	3.9	questionable
Arctogadus glacialis	Arctic cod	Gadidae	bathypelagic	32.5 TL	3.8	questionable
Boreogadus saida	Polar cod	Gadidae	demersal	40.0 TL	3.1	native
Eleginus gracilis	Saffron cod	Gadidae	demersal	55.0 TL	4.1	native

Species	Name	Family	Habitat	Length (cm)	Trophic Level	Status
Eleginus nawaga	Navaga	Gadidae	demersal	42.0 TL	4.2	native
Gadus ogac	Greenland cod	Gadidae	demersal	77.0 TL	3.6	native
Pollachius virens	Saithe	Gadidae	demersal	130.0 TL	4.4	native
Theragra chalcogramma	Alaska pollock	Gadidae	benthopelagic	91.0 TL	3.5	native
Pungitius pungitius	Ninespine stickleback	Gasterosteidae	benthopelagic	9.0 TL	3.3	native
Hexagrammos stelleri	Whitespotted greenling	Hexagrammidae	demersal	48.0 TL	3.3	native
Liparis bristolensis		Liparidae	demersal	20.0 TL	3.4	native
Liparis fabricii	Gelatinous snailfish	Liparidae	bathydemersal	20.0 TL	3.3	native
Liparis gibbus	Variegated snailfish	Liparidae	demersal	52.0 TL	3.3	native
Liparis tunicatus	Kelp snailfish	Liparidae	demersal	16.0 TL	3.5	native
Benthosema glaciale	Glacier lanternfish	Myctophidae	pelagic-oceanic	12.6 TL	3.0	native
Mallotus villosus	Capelin	Osmeridae	pelagic-oceanic	25.2 TL	3.2	native
Osmerus mordax dentex	Arctic rainbow smelt	Osmeridae	pelagic-neritic	32.4 TL	4.2	native
Lampetra camtschatica	Arctic lamprey	Petromyzontidae	demersal	63.0 TL	4.5	native
Petromyzon marinus	Sea lamprey	Petromyzontidae	demersal	120.0 TL	4.4	native
Pholis fasciata	Banded gunnel	Pholidae	demersal	30.0 TL	3.3	native
Pholis gunnellus	Rock gunnel	Pholidae	demersal	30.5 TL	3.5	native
Atheresthes stomias	Arrowtooth flounder	Pleuronectidae	demersal	84.0 TL	4.3	native
Hippoglossoides robustus	Bering flounder	Pleuronectidae	demersal	36.6 TL	3.1	native
Hippoglossus stenolepis	Pacific halibut	Pleuronectidae	demersal	267.0 TL	4.1	native
Limanda aspera	Yellowfin	Pleuronectidae	demersal	49.0	3.2	native

Species	Name	Family	Habitat	Length (cm)	Trophic Level	Status
	sole			TL		
Liopsetta glacialis	Arctic flounder	Pleuronectidae	demersal	35.0 TL	3.2	native
Platichthys flesus	Flounder	Pleuronectidae	demersal	60.0 TL	3.2	native
Platichthys stellatus	Starry flounder	Pleuronectidae	demersal	91.0 TL	3.3	native
Pleuronectes quadrituberculatus	Alaska plaice	Pleuronectidae	demersal	62.0 TL	3.1	native
Reinhardtius hippoglossoides	Greenland halibut	Pleuronectidae	benthopelagic	120.0 TL	4.5	native
Amblyraja radiata	Thorny skate	Rajidae	demersal	105.0 TL	4.0	native
Coregonus autumnalis	Arctic cisco	Salmonidae	pelagic-neritic	64.0 TL	3.6	native
Coregonus laurettae	Bering cisco	Salmonidae	pelagic-neritic	53.3 TL	3.8	native
Coregonus nasus	Broad whitefish	Salmonidae	demersal	71.0 TL	3.3	native
Coregonus pidschian	Humpback whitefish	Salmonidae	demersal	46.0 TL	3.2	native
Coregonus sardinella	Sardine cisco	Salmonidae	pelagic-neritic	47.0 TL	3.2	native
Oncorhynchus gorbuscha	Pink salmon	Salmonidae	demersal	76.0 TL	4.2	native
Oncorhynchus keta	Chum salmon	Salmonidae	benthopelagic	111.0 TL	3.5	native
Oncorhynchus kisutch	Coho salmon	Salmonidae	demersal	107.9 TL	4.2	native
Oncorhynchus mykiss	Rainbow trout	Salmonidae	benthopelagic	120.0 TL	4.4	native
Oncorhynchus nerka	Sockeye salmon	Salmonidae	pelagic-oceanic	84.0 TL	3.7	native
Oncorhynchus tshawytscha	Chinook salmon	Salmonidae	benthopelagic	150.0 TL	4.4	native
Salmo salar	Atlantic salmon	Salmonidae	benthopelagic	150.0 TL	4.4	native
Salvelinus alpinus alpinus	Charr	Salmonidae	benthopelagic	107.0 TL	4.3	native
Salvelinus malma malma	Dolly varden	Salmonidae	benthopelagic	127.0 TL	4.2	native

Species	Name	Family	Habitat	Length (cm)	Trophic Level	Status
Somniosus microcephalus	Greenland shark	Somniosidae	benthopelagic	730.0 TL	4.2	native
Somniosus pacificus	Pacific sleeper shark	Somniosidae	benthopelagic	440.0 TL	4.3	native
Acantholumpenus mackayi	Pighead prickleback	Stichaeidae	demersal	85.4 TL	3.1	native
Anisarchus medius	Stout eelblenny	Stichaeidae	demersal	30.0 TL	3.2	native
Eumesogrammus praecisus	Fourline snakeblenny	Stichaeidae	benthopelagic	22.0 TL	3.5	native
Leptoclinus maculatus	Daubed shanny	Stichaeidae	demersal	20.0 TL	3.0	native
Lumpenus fabricii	Slender eelblenny	Stichaeidae	demersal	50.5 TL	3.3	native
Stichaeus punctatus punctatus	Arctic shanny	Stichaeidae	demersal	22.0 TL	3.1	native
Gymnelus hemifasciatus	Bigeye unernak	Zoarcidae	demersal	12.8 TL	3.1	native
Gymnelus viridis	Fish doctor	Zoarcidae	demersal	56.0 TL	3.1	native
Lycenchelys kolthoffi	Checkered wolf eel	Zoarcidae	bathydemersal	28.3 TL	3.1	native
Lycodes eudipleurostictus	Doubleline eelpout	Zoarcidae	demersal	54.3 TL	3.5	native
Lycodes jugoricus	Shulupaoluk	Zoarcidae	demersal	25.7 TL	3.2	native
Lycodes mucosus	Saddled eelpout	Zoarcidae	demersal	24.9 TL	3.9	native
Lycodes palearis	Wattled eelpout	Zoarcidae	bathydemersal	51.0 TL	3.5	native
Lycodes pallidus	Pale eelpout	Zoarcidae	demersal	26.0 TL	3.3	native
Lycodes polaris	Canadian eelpout	Zoarcidae	demersal	25.0 TL	3.3	native
Lycodes raridens	Marbled eelpout	Zoarcidae	demersal	77.0 TL	3.2	native
Lycodes reticulatus	Arctic eelpout	Zoarcidae	bathydemersal	36.0 TL	3.5	native
Lycodes rossi	Threespot eelpout	Zoarcidae	demersal	31.0 TL	3.5	native
Lycodes	Archer	Zoarcidae	bathydemersal	33.3	3.2	native

Species	Name	Family	Habitat	Length (cm)	Trophic Level	Status
sagittarius	eelpout			TL		
Lycodes seminudus	Longear eelpout	Zoarcidae	bathydemersal	51.7 TL	3.5	native
Lycodes squamiventer	Scalebelly eelpout	Zoarcidae	bathydemersal	26.0 TL	3.4	native
Lycodes turneri	Polar eelpout	Zoarcidae	demersal	25.0 TL	3.4	native

APPENDIX B

MARINE FISH OF THE CHUKCHI SEA AND ARCTIC OCEAN. FROM FISHBASE.ORG

Species	Name	Family	Habitat	Length (cm)	Trophic Level	Status
Aspidophoroides bartoni	Aleutian alligatorfish	Agonidae	demersal	22.0 TL	3.3	native
Occella dodecaedron	Bering poacher	Agonidae	demersal	26.4 TL	3.2	native
Podothecus accipenserinus	Sturgeon poacher	Agonidae	demersal	30.5 TL	3.4	native
Ulcina olrikii	Arctic alligatorfish	Agonidae	demersal	8.6 TL	3.3	native
Ammodytes hexapterus	Pacific sand lance	Ammodytidae	benthopelagic	30.0 TL	3.1	native
Anarrhichthys ocellatus	Wolf-eel	Anarhichadidae	demersal	240.0 TL	3.5	native
Bathymaster signatus	Searcher	Bathymasteridae	demersal	38.0 TL	3.5	native
Clupea pallasii pallasii	Pacific herring	Clupeidae	pelagic-neritic	46.0 TL	3.2	native
Artediellus scaber	Hamecon	Cottidae	demersal	8.4 TL	3.3	native
Gymnocanthus pistilliger	Threaded sculpin	Cottidae	demersal	28.0 TL	3.1	native
Gymnocanthus tricuspis	Arctic staghorn sculpin	Cottidae	demersal	30.0 TL	3.5	native
Hemilepidotus papilio	Butterfly sculpin	Cottidae	demersal	36.6 TL	3.3	native
Hemilepidotus zapus	Longfin Irish lord	Cottidae	demersal	26.0 TL	3.4	native
Icelus bicornis	Twohorn sculpin	Cottidae	demersal	19.1 TL	3.1	native
Icelus spatula	Spatulate sculpin	Cottidae	demersal	21.0 TL	3.9	native
Megalocottus platycephalus platycephalus	Belligerent sculpin	Cottidae	demersal	42.0 TL	4.1	native

Species	Name	Family	Habitat	Length (cm)	Trophic Level	Status
Myoxocephalus jaok	Plain sculpin	Cottidae	demersal	74.0 TL	4.2	native
Myoxocephalus scorpioides	Arctic sculpin	Cottidae	demersal	22.0 TL	3.4	native
Myoxocephalus scorpius	Shorthorn sculpin	Cottidae	demersal	60.0 TL	3.9	native
Myoxocephalus stelleri	Steller's sculpin	Cottidae	reef-associated	60.0 TL	3.9	native
Myoxocephalus verrucosus	Warty sculpin	Cottidae	demersal	30.0 TL	3.7	native
Triglops pingelii	Ribbed sculpin	Cottidae	demersal	24.6 TL	3.4	native
Triglopsis quadricornis	Fourhorn sculpin	Cottidae	demersal	60.0 TL	3.7	native
Eumicrotremus andriashevi	Pimpled lumpsucker	Cyclopteridae	demersal	5.9 TL	3.2	native
Eumicrotremus derjugini	Leatherfin lumpsucker	Cyclopteridae	demersal	12.2 TL	3.3	native
Eumicrotremus orbis	Pacific spiny lumpsucker	Cyclopteridae	demersal	18.0 TL	3.2	native
Arctogadus borisovi	East Siberian cod	Gadidae	demersal	55.6 TL	3.9	native
Arctogadus glacialis	Arctic cod	Gadidae	bathypelagic	32.5 TL	3.8	native
Boreogadus saida	Polar cod	Gadidae	demersal	40.0 TL	3.1	native
Eleginus gracilis	Saffron cod	Gadidae	demersal	55.0 TL	4.1	native
Eleginus nawaga	Navaga	Gadidae	demersal	42.0 TL	4.2	native
Gadus ogac	Greenland cod	Gadidae	demersal	77.0 TL	3.6	native
Theragra chalcogramma	Alaska pollock	Gadidae	benthopelagic	91.0 TL	3.5	native
Pungitius pungitius	Ninespine stickleback	Gasterosteidae	benthopelagic	9.0 TL	3.3	native
Hexagrammos stelleri	Whitespotted greenling	Hexagrammidae	demersal	48.0 TL	3.3	native
Liparis bristolensis		Liparidae	demersal	20.0 TL	3.4	questionable
Liparis gibbus	Variegated snailfish	Liparidae	demersal	52.0 TL	3.3	native

Species	Name	Family	Habitat	Length (cm)	Trophic Level	Status
Mallotus villosus	Capelin	Osmeridae	pelagic-oceanic	25.2 TL	3.2	native
Osmerus mordax dentex	Arctic rainbow smelt	Osmeridae	pelagic-neritic	32.4 TL	4.2	native
Lampetra camtschatica	Arctic lamprey	Petromyzontidae	demersal	63.0 TL	4.5	native
Atheresthes stomias	Arrowtooth flounder	Pleuronectidae	demersal	84.0 TL	4.3	questionable
Hippoglossoides robustus	Bering flounder	Pleuronectidae	demersal	36.6 TL	3.1	native
Hippoglossus stenolepis	Pacific halibut	Pleuronectidae	demersal	267.0 TL	4.1	native
Limanda aspera	Yellowfin sole	Pleuronectidae	demersal	49.0 TL	3.2	native
Limanda proboscidea	Longhead dab	Pleuronectidae	demersal	48.8 TL	3.1	native
Liopsetta glacialis	Arctic flounder	Pleuronectidae	demersal	35.0 TL	3.2	native
Platichthys stellatus	Starry flounder	Pleuronectidae	demersal	91.0 TL	3.3	native
Pleuronectes quadrituberculatus	Alaska plaice	Pleuronectidae	demersal	62.0 TL	3.1	native
Reinhardtius hippoglossoides	Greenland halibut	Pleuronectidae	benthopelagic	120.0 TL	4.5	native
Coregonus autumnalis	Arctic cisco	Salmonidae	pelagic-neritic	64.0 TL	3.6	native
Coregonus laurettae	Bering cisco	Salmonidae	pelagic-neritic	53.3 TL	3.8	native
Coregonus nasus	Broad whitefish	Salmonidae	demersal	71.0 TL	3.3	native
Coregonus pidschian	Humpback whitefish	Salmonidae	demersal	46.0 TL	3.2	native
Coregonus sardinella	Sardine cisco	Salmonidae	pelagic-neritic	47.0 TL	3.2	native
Oncorhynchus gorbuscha	Pink salmon	Salmonidae	demersal	76.0 TL	4.2	native
Oncorhynchus keta	Chum salmon	Salmonidae	benthopelagic	111.0 TL	3.5	native
Oncorhynchus kisutch	Coho salmon	Salmonidae	demersal	107.9 TL	4.2	native
Oncorhynchus	Rainbow	Salmonidae	benthopelagic	120.0	4.4	native

Species	**Name**	**Family**	**Habitat**	**Length (cm)**	**Trophic Level**	**Status**
mykiss	trout			TL		
Oncorhynchus nerka	Sockeye salmon	Salmonidae	pelagic-oceanic	84.0 TL	3.7	native
Oncorhynchus tshawytscha	Chinook salmon	Salmonidae	benthopelagic	150.0 TL	4.4	native
Salvelinus alpinus alpinus	Charr	Salmonidae	benthopelagic	107.0 TL	4.3	native
Salvelinus malma malma	Dolly varden	Salmonidae	benthopelagic	127.0 TL	4.2	native
Somniosus microcephalus	Greenland shark	Somniosidae	benthopelagic	730.0 TL	4.2	native
Somniosus pacificus	Pacific sleeper shark	Somniosidae	benthopelagic	440.0 TL	4.3	native
Acantholumpenus mackayi	Pighead prickleback	Stichaeidae	demersal	85.4 TL	3.1	native
Anisarchus medius	Stout eelblenny	Stichaeidae	demersal	30.0 TL	3.2	native
Eumesogrammus praecisus	Fourline snakeblenny	Stichaeidae	benthopelagic	22.0 TL	3.5	native
Leptoclinus maculatus	Daubed shanny	Stichaeidae	demersal	20.0 TL	3.0	native
Lumpenus fabricii	Slender eelblenny	Stichaeidae	demersal	50.5 TL	3.3	native
Stichaeus punctatus punctatus	Arctic shanny	Stichaeidae	demersal	22.0 TL	3.1	native
Gymnelus platycephalus		Zoarcidae	demersal	17.1 TL	3.1	native
Lycodes eudipleurostictus	Doubleline eelpout	Zoarcidae	demersal	54.3 TL	3.5	native
Lycodes jugoricus	Shulupaoluk	Zoarcidae	demersal	25.7 TL	3.2	native
Lycodes mucosus	Saddled eelpout	Zoarcidae	demersal	24.9 TL	3.9	native
Lycodes palearis	Wattled eelpout	Zoarcidae	bathydemersal	51.0 TL	3.5	native
Lycodes pallidus	Pale eelpout	Zoarcidae	demersal	26.0 TL	3.3	native
Lycodes polaris	Canadian eelpout	Zoarcidae	demersal	25.0 TL	3.3	native
Lycodes raridens	Marbled eelpout	Zoarcidae	demersal	77.0 TL	3.2	native

Species	Name	Family	Habitat	Length (cm)	Trophic Level	Status
Lycodes rossi	Threespot eelpout	Zoarcidae	demersal	31.0 TL	3.5	native
Lycodes sagittarius	Archer eelpout	Zoarcidae	bathydemersal	33.3 TL	3.2	native
Lycodes seminudus	Longear eelpout	Zoarcidae	bathydemersal	51.7 TL	3.5	native
Lycodes turneri	Polar eelpout	Zoarcidae	demersal	25.0 TL	3.4	native

APPENDIX C:

REVIEW OF THE EFFECTS OF AIRGUN SOUNDS ON MARINE MAMMALS[2]

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 (adapted from 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, either without or with some deleterious effects (e.g., masking, stress);
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.

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[2] By **W. John Richardson** and **Valerie D. Moulton**, with subsequent updates (to Dec. 2009) by WJR and VDM plus **Patrick Abgrall**, **William E. Cross**, **Meike Holst**, and **Mari A. Smultea**, all of LGL Ltd., environmental research associates

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

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

2.1 Toothed Whales (Odontocetes)

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

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; Parks et al. 2007b). Although humpbacks and minke whales (Berta et al. 2009) may have some auditory sensitivity to frequencies above 22 kHz, for baleen whales as a group, the functional hearing range is thought to be about 7 Hz to 22 kHz and they are said to 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, 2009). The functional hearing range for pinnipeds in water is considered to extend from 75 Hz to 75 kHz (Southall et al. 2007), although some individual species—especially the eared seals—do not have that broad an auditory range (Richardson et al. 1995). In comparison with odontocetes, pinnipeds tend to have lower best frequencies, lower high-frequency cutoffs, better auditory sensitivity at low frequencies, and poorer sensitivity at the best frequency.

At least some of the phocid seals have better sensitivity at low frequencies (≤1 kHz) than do odontocetes. Below 30–50 kHz, the hearing thresholds of most species tested are essentially flat down to ~1 kHz, and range between 60 and 85 dB re 1 µPa. Measurements for harbor seals indicate that, below 1 kHz, their thresholds under quiet background conditions deteriorate gradually with decreasing frequency to ~75 dB re 1 µPa at 125 Hz (Kastelein et al. 2009).

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 and low-frequency vibrations from 15 Hz to 46 kHz, based on a study involving behavioral testing methods (Gerstein et al. 1999, 2004). A more recent study found that, in one Florida manatee, auditory sensitivity extended up to 90.5 kHz (Bauer et al. 2009). 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 tests suggest that best sensitivities are at 6–20 kHz (Gerstein et al. 1999) or 8–32 kHz (Bauer et al. 2009). 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, 2004).

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). However, Ghoul et al. (2009) noted that the in-air “screams” of sea otters are loud signals (source level of 93–118 dB re 20 μPa_{pk}) that may be used over larger distances; screams have a frequency of maximum energy ranging from 2 to 8 kHz. 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 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 36-airgun arrays used by Lamont-Doherty Earth Observatory (L-DEO) from the R/V *Maurice Ewing* (now retired) and R/V *Marcus G. Langseth* (36 airguns) are 236–265 dB re 1 μPa_{p-p}. These are the nominal source levels applicable to downward propagation. The effective source levels for horizontal propagation are lower than those for downward propagation when the source consists of numerous airguns spaced apart from one another. Explosions are the only man-made sources with effective source levels as high as (or higher than) a large array of airguns. However, high-power sonars can have source pressure levels as high as a small array of airguns, and signal duration can be longer for a sonar than for an airgun array, making the source energy levels of some sonars more comparable to those of airgun arrays.

Several important mitigating factors need to be kept in mind. (1) Airgun arrays produce intermittent sounds, involving emission of a strong sound pulse for a small fraction of a second followed by several seconds of near silence. In contrast, some other sources produce sounds with lower peak levels, but their sounds are continuous or discontinuous but continuing for longer durations than 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 $\mu Pa \cdot m$. 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.[3] 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

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

(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 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. However, it is common for reverberation to cause some lesser degree of elevation of the background level between airgun pulses (e.g., Guerra et al. 2009), and this weaker reverberation presumably reduces the detection range of calls and other natural sounds to some degree.

Although masking effects of pulsed sounds on marine mammal calls and other natural sounds are expected to be limited, there are few specific studies on this. Some whales continue calling in the presence of seismic pulses and whale calls often can be heard between the seismic pulses (e.g., Richardson et al. 1986; McDonald et al. 1995; Greene et al. 1999a,b; Nieukirk et al. 2004; Smultea et al. 2004; Holst et al. 2005a,b, 2006; Dunn and Hernandez 2009). 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. Also, bowhead whales in the Beaufort Sea may decrease their call rates in response to seismic operations, although movement out of the area might also have contributed to the lower call detection rate (Blackwell et al. 2009a,b). In contrast, Di Iorio and Clark (2009) found evidence of *increased* calling by blue whales during operations by a lower-energy seismic source—a sparker.

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. 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, shift their peak frequencies in response to strong sound signals, or otherwise modify their vocal behavior in response to increased noise (Dahlheim 1987; Au 1993; reviewed in Richardson et al. 1995:233*ff*, 364*ff*; Lesage et al. 1999; Terhune 1999; Nieukirk et al. 2005; Scheifele et al. 2005; Parks et al. 2007a, 2009; Di Iorio and Clark 2009; Hanser et al. 2009). It is not known how often these types of responses occur upon exposure to airgun sounds. However, blue whales in the St. Lawrence Estuary significantly increased their call rates during sparker operations (Di Iorio and Clark 2009). The sparker, used to obtain seismic reflection data, emitted frequencies of 30–450 Hz with a relatively low source level of 193 dB re 1 μPa_{pk-pk}. If cetaceans exposed to airgun sounds sometimes respond by changing their vocal behavior, this adaptation, along with directional hearing and preadaptation to tolerate some masking by natural sounds (Richardson et al. 1995), would all reduce the importance of masking by seismic pulses.

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 not 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). Also, various authors have noted that some marine mammals that show no obvious avoidance or behavioral changes may still be adversely affected by noise (Brodie 1981; Richardson et al. 1995:317*ff*; Romano et al. 2004; Weilgart 2007; Wright et al. 2009). For example, some research suggests that animals in poor condition or in an already stressed state may not react as strongly to human disturbance as would more robust animals (e.g., Beale and Monaghan 2004).

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

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

The definitions of “taking” in the U.S. MMPA, and its applicability to various activities, were slightly altered in November 2003 for military and federal scientific research activities. Also, NMFS is proposing to replace current Level A and B harassment criteria with guidelines based on exposure characteristics that are specific to particular groups of mammal species and to particular sound types (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 μPa_{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 μPa_{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 $\mu Pa \cdot m_{p\text{-}p}$. 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 μPa_{rms} (McCauley et al. 1998, 2000a). A greater stand-off range of 7–12 km was observed for more sensitive resting pods (cow-calf pairs; McCauley et al. 1998, 2000a). The mean received level for initial avoidance of an approaching airgun was 140 dB re 1 μPa_{rms} for humpback pods containing females, and at the mean CPA distance the received level was 143 dB re 1 μPa_{rms}. One startle response was reported at 112 dB re 1 μPa_{rms}. The initial avoidance response generally occurred at distances of 5–8 km from the airgun array and 2 km from the single airgun. However, some individual humpback whales, especially males, approached within distances of 100–400 m, where the maximum received level was 179 dB re 1 μPa_{rms}. The McCauley et al. (1998, 2000a,b) studies show evidence of greater avoidance of seismic airgun sounds by pods with females than by other pods during humpback migration off Western Australia.

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). They also moved away when a single airgun fired nearby (Richardson et al. 1986; Ljungblad et al. 1988). In one case, bowheads engaged in near-bottom feeding began to turn away from a 30-airgun array with a source level of 248 dB re 1 µPa·m at a distance of 7.5 km, and swam away when it came within ~2 km; some whales continued feeding until the vessel was 3 km away (Richardson et al. 1986). This work and subsequent summer studies in the same region 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 (see below) before showing an overt change in behavior. On the summer 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. Similarly, preliminary analyses of recent data from the Alaskan Beaufort Sea indicate that bowheads feeding there during late summer and autumn also did not display large-scale distributional changes in relation to seismic operations (Christie et al. 2009; Koski et al. 2009). However, some individual bowheads apparently begin to react at distances a few 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; see also Manly et al. 2007). Those results came from 1996–98, when a partially-controlled study of the effect of Ocean Bottom Cable (OBC) seismic surveys on westward-migrating bowheads was conducted in late summer and autumn in the Alaskan Beaufort Sea. At times when the airguns were not active, many bowheads moved into the area close to the inactive seismic vessel. Avoidance of the area of seismic operations did not persist beyond 12–24 h after seismic shooting stopped. Preliminary analysis of recent data on traveling bowheads in the Alaskan Beaufort Sea also showed a stronger tendency to avoid operating airguns than was evident for feeding bowheads (Christie et al. 2009; Koski et al. 2009).

Bowhead whale calls detected in the presence and absence of airgun sounds have been studied extensively in the Beaufort Sea. Early work on the summering grounds in the Canadian Beaufort Sea showed that bowheads continue to produce calls of the usual types when exposed to airgun sounds, although numbers of calls detected may be somewhat lower in the presence of airgun pulses (Richardson et al. 1986). Studies during autumn in the Alaskan Beaufort Sea, one in 1996–1998 and another in 2007–2008, have shown that numbers of calls detected are significantly lower in the presence than in the absence of airgun pulses (Greene et al. 1999a,b; Blackwell et al. 2009a,b; Koski et al. 2009; see also Nations et al. 2009). This decrease could have resulted from movement of the whales away from the area of the seismic survey or a reduction in calling behavior, or a combination of the two. However, concurrent aerial surveys showed that there was strong avoidance of the operating airguns during the 1996–98 study, when most of the whales appeared to be migrating (Miller et al. 1999; Richardson et al. 1999). In contrast, aerial surveys during the 2007–08 study showed less consistent avoidance by the bowheads, many of which appeared to be feeding (Christie et al. 2009; Koski et al. 2009). The reduction in call detection rates during periods of airgun operation may have been more dependent on actual avoidance during the 1996–98 study and more dependent on reduced calling behavior during the 2007–08 study, but further analysis of the recent data is ongoing.

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). 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 seen in areas ensonified by airgun pulses (Stone 2003; MacLean and Haley 2004; Stone and Tasker 2006), and calls from blue and fin whales have been localized in areas with airgun operations (e.g., McDonald et al. 1995; Dunn and Hernandez 2009). 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.[4] 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).

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[4] 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.

***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 support vessels operating in coordination with the seismic vessel (e.g., Smultea et al. 2004; Johnson et al. 2007). However, the presence of other vessels near the source vessel can, at least at times, reduce sightability of cetaceans from the source vessel (Beland et al. 2009), thus complicating interpretation of sighting data.

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

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).

Mitigation measures for seismic surveys, especially nighttime seismic surveys, typically assume that many marine mammals (at least baleen whales) tend to avoid approaching airguns, or the seismic vessel itself, before being exposed to levels high enough for there to be any possibility of injury. This assumes that the ramp-up (soft-start) procedure is used when commencing airgun operations, to give whales near the vessel the opportunity to move away before they are exposed to sound levels that might be strong enough to elicit TTS. As noted above, single-airgun experiments with three species of baleen whales show that those species typically do tend to move away when a single airgun starts firing nearby, which simulates the onset of a ramp up. The three species that showed avoidance when exposed to the onset of pulses from a single airgun were *gray whales* (Malme et al. 1984, 1986, 1988); *bowhead whales* (Richardson et al. 1986; Ljungblad et al. 1988); and *humpback whales* (Malme et al. 1985; McCauley et al. 1998, 2000a,b). Since startup of a single airgun is equivalent to the start of a ramp-up (=soft start), this strongly suggests that many baleen whales will begin to move away during the initial stages of a ramp-up.

Data on short-term reactions by cetaceans to impulsive noises are not necessarily indicative of long-term or biologically significant effects. It is not known whether impulsive sounds affect reproductive rate or distribution and habitat use in subsequent days or years. 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 (e.g., Gordon et al. 2006; Madsen et al. 2006; Winsor and Mate 2006; Jochens et al. 2008; Miller et al. 2009). There is also an increasing amount of information about responses of various odontocetes to seismic surveys based on monitoring studies (e.g., Stone 2003; Smultea et al. 2004; Moulton and Miller 2005; Bain and Williams 2006; Holst et al. 2006; Stone and Tasker 2006; Potter et al. 2007; Hauser et al. 2008; Holst and Smultea 2008; Weir 2008a; Barkaszi et al. 2009; Richardson et al. 2009).

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; Richardson et al. 2009; see also Barkaszi et al. 2009). 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 how effective it is at alerting marine mammals (especially odontocetes) 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[5] 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 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.

Data collected during seismic operations in the Gulf of Mexico and off Central America show similar patterns. A summary of vessel-based monitoring data from the Gulf of Mexico during 2003–2008 showed that delphinids were generally seen farther from the vessel during seismic than during non-seismic periods (based on Barkaszi et al. 2009, excluding sperm whales). Similarly, during two NSF-funded L-DEO seismic surveys that used a large 20 airgun array (~7000 in^3), sighting rates of delphinids were lower and initial sighting distances were farther away from the vessel during seismic than non-seismic periods (Smultea et al. 2004; Holst et al. 2005a, 2006; Richardson et al. 2009). Monitoring results during a seismic survey in the Southeast Caribbean showed that the mean CPA of delphinids was 991 m during seismic operations vs. 172 m when the airguns were not operational (Smultea et al. 2004).

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

Surprisingly, nearly all acoustic detections via a towed passive acoustic monitoring (PAM) array, including both delphinids and sperm whales, were made when the airguns were operating (Smultea et al. 2004). Although the number of sightings during monitoring of a seismic survey off the Yucatán Peninsula, Mexico, was small (*n* = 19), the results showed that the mean CPA distance of delphinids there was 472 m during seismic operations vs. 178 m when the airguns were silent (Holst et al. 2005a). The acoustic detection rates were nearly 5 times higher during non-seismic compared with seismic operations (Holst et al. 2005a).

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

During two seismic surveys off Newfoundland and Labrador in 2004–05, dolphin sighting rates were lower during seismic periods than during non-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 farther during seismic periods (807 vs. 652 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[6] airgun sources were operating, and effects on orientation were evident for all species and groups tested (Stone and Tasker 2006). Results from four NSF-funded L-DEO seismic surveys using small arrays (up to 3 GI guns and 315 in^3) were inconclusive. During surveys in the Eastern Tropical Pacific (Holst et al. 2005b) and in the Northwest Atlantic (Haley and Koski 2004), detection rates were slightly lower during 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 both surveys was small. Results from another two small-array surveys were even more variable (MacLean and Koski 2005; Smultea and Holst 2008).

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

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

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). A captive harbor porpoise exposed to single sound pulses from a small airgun showed aversive behavior upon receipt of a pulse with received level above 174 dB re 1 μPa_{pk-pk} or SEL >145 dB re 1 $\mu Pa^2 \cdot s$ (Lucke et al. 2009). 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, other visual and acoustic studies indicated that some northern bottlenose whales remained in the general area and continued to produce high-frequency clicks when exposed to sound pulses from distant seismic surveys (Gosselin and Lawson 2004; Laurinolli and Cochrane 2005; Simard et al. 2005).

There are increasing indications that some beaked whales tend to strand when military exercises involving mid-frequency sonar operation are ongoing nearby (e.g., Simmonds and Lopez-Jurado 1991; Frantzis 1998; NOAA and USN 2001; Jepson et al. 2003; Barlow and Gisiner 2006; 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; Winsor and Mate 2006; Jochens et al. 2008; Miller et al. 2009).

Recent and more extensive data from vessel-based monitoring programs in U.K. waters and off 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 μPa_{p-p} (Madsen et al. 2002).

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

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

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

Discussion and Conclusions.—Dolphins and porpoises are often seen by observers on active seismic vessels, occasionally at close distances (e.g., bow riding). However, some studies near the U.K., Newfoundland and Angola, in the Gulf of Mexico, and off Central America have shown localized avoidance. Also, 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. With a medium-to-large airgun array, received levels typically diminish to 170 dB within 1–4 km, whereas levels typically remain above 160 dB out to 4–15 km (e.g., Tolstoy et al. 2009). Reaction distances for delphinids are more consistent with the typical 170 dB re 1 μPa_{rms} distances. The 160 dB (rms) criterion currently applied by NMFS was developed based primarily on data from gray and bowhead whales. Avoidance distances for delphinids and Dall's porpoises tend to be shorter than for those two mysticete species. For delphinids and Dall's porpoises, there is no indication of strong avoidance or other disruption of behavior at distances beyond those where received levels would be ~170 dB re 1 μPa_{rms}.

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. Additional monitoring of that type has been done in the Beaufort and Chukchi Seas in 2006–2009. Pinnipeds exposed to seismic surveys have also been observed during seismic surveys along the U.S. west coast. Some limited data are available on physiological responses of pinnipeds exposed to seismic sound, as studied with the aid of radio telemetry. Also, there are data on the reactions of pinnipeds to various other related types of impulsive sounds.

Early observations provided considerable evidence that pinnipeds are often quite tolerant of strong pulsed sounds. During seismic exploration off Nova Scotia, gray seals exposed to 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.

Vessel-based monitoring also took place in the Alaskan Chukchi and Beaufort seas during 2006–2008 (Reiser et al. 2009). Observers on the seismic vessels saw phocid seals less frequently while airguns were operating than when airguns were silent. Also, during airgun operations, those observers saw seals less frequently than did observers on nearby vessels without airguns. Finally, observers on the latter "no-airgun" vessels saw seals more often when the nearby source vessels' airguns were operating than when they were silent. All of these observations are indicative of a tendency for phocid seals to exhibit localized avoidance of the seismic source vessel when airguns are firing (Reiser et al. 2009).

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

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 late 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.

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

On the other hand, the TTS threshold for odontocetes exposed to a single impulse from a watergun (Finneran et al. 2002) appeared to be somewhat lower than for exposure to non-impulse sound. This was expected, based on evidence from terrestrial mammals showing that broadband pulsed sounds with rapid rise times have greater auditory effect than do non-impulse sounds (Southall et al. 2007). The received energy level of a single seismic pulse that caused the onset of mild TTS in the beluga, as measured without frequency weighting, was ~186 dB re 1 $\mu Pa^2 \cdot s$ or 186 dB SEL (Finneran et al. 2002).[7] The rms level of an airgun pulse (in dB re 1 μPa measured over the duration of the pulse) is typically 10–15 dB higher than the SEL for the same pulse when received within a few 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

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

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.

The above TTS information for odontocetes is derived from studies on the bottlenose dolphin and beluga. For the one harbor porpoise tested, the received level of airgun sound that elicited onset of TTS was lower. The animal was exposed to single pulses from a small (20 in^3) airgun, and auditory evoked potential methods were used to test the animal's hearing sensitivity at frequencies of 4, 32, or 100 kHz after each exposure (Lucke et al. 2009). Based on the measurements at 4 kHz, TTS occurred upon exposure to one airgun pulse with received level ~200 dB re 1 μPa_{pk-pk} or an SEL of 164.3 dB re 1 $\mu Pa^2 \cdot s$. If these results from a single animal are representative, it is inappropriate to assume that onset of TTS occurs at similar received levels in all odontocetes (*cf.* Southall et al. 2007). Some cetaceans may incur TTS at lower sound exposures than are necessary to elicit TTS in the beluga or bottlenose dolphin.

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

Additional data are needed to determine the received sound levels at which small odontocetes would start to incur TTS upon exposure to repeated, low-frequency pulses of airgun sound with variable received levels. To determine how close an airgun array would need to approach in order to elicit TTS, 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 (e.g., Erbe and King 2009). At the present state of knowledge, it is also necessary to assume that the effect is directly related to total received energy even though that energy is received in multiple pulses separated by gaps. The lack of data on the exposure levels necessary to cause TTS in toothed whales when the signal is a series of pulsed sounds, separated by silent periods, remains a data gap, as is the lack of published data on TTS in odontocetes other than the beluga, bottlenose dolphin, and harbor porpoise.

Baleen Whales.—There are no data, direct or indirect, on levels or properties of sound that are required to induce TTS in any baleen whale. The frequencies to which mysticetes are most sensitive are assumed to be lower than those to which odontocetes are most sensitive, and natural background noise levels at those low frequencies tend to be higher. As a result, auditory thresholds of baleen whales within their frequency band of best hearing are believed to be higher (less sensitive) than are those of odontocetes at their best frequencies (Clark and Ellison 2004). From this, it is suspected that received levels causing TTS onset may also be higher in mysticetes (Southall et al. 2007). However, based on preliminary simulation modeling that attempted to allow for various uncertainties in assumptions and variability around population means, Gedamke et al. (2008) suggested that some baleen whales whose closest point of approach to a seismic vessel is 1 km or more could experience TTS or even PTS.

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

Pinnipeds.—In pinnipeds, TTS thresholds associated with exposure to brief pulses (single or multiple) of underwater sound have not been measured. Two California sea lions did not incur TTS when exposed to single brief pulses with received levels of ~178 and 183 dB re 1 μPa_{rms} and total 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 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 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 generally not as strong or consistent as those of cetaceans. Pinnipeds occasionally seem to be attracted to operating seismic vessels. There are no specific data on TTS thresholds of pinnipeds exposed to single or multiple low-frequency pulses. However, given the indirect indications of a lower TTS threshold for the harbor seal than for odontocetes exposed to impulse sound (see above), it is possible that some pinnipeds close to a large airgun array could incur TTS.

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

It has been shown that most large whales and many smaller odontocetes (especially the harbor porpoise) show at least localized avoidance of ships and/or seismic operations (see above). Even when avoidance is limited to the area within a few hundred meters of an airgun array, that should usually be sufficient to avoid TTS based on what is currently known about thresholds for TTS onset in cetaceans. In addition, ramping up airgun arrays, which is standard operational protocol for many seismic operators, should allow cetaceans near the airguns at the time of startup (if the sounds are aversive) to move away from the seismic source and to avoid being exposed to the full acoustic output of the airgun array (see above). Thus, most baleen whales likely will not be exposed to high levels of airgun sounds provided the ramp-up procedure is applied. Likewise, many odontocetes close to the trackline are likely to move away before the sounds from an approaching seismic vessel become sufficiently strong for there to be any potential for TTS or other hearing impairment. Therefore, there is little potential for baleen whales or odontocetes that show avoidance of ships or airguns to be close enough to an airgun array to experience TTS. In the event that a few individual cetaceans did incur TTS through exposure to strong airgun sounds, this is a temporary and reversible phenomenon unless the exposure exceeds the TTS-onset threshold by a sufficient amount for PTS to be incurred (see below). If TTS but not PTS were incurred, it would most likely be mild, in which case recovery is expected to be quick (probably within minutes).

6.2 Permanent Threshold Shift (PTS)

When PTS occurs, there is physical damage to the sound receptors in the ear. In some cases, there can be total or partial deafness, whereas in other cases, the animal has an impaired ability to hear sounds in specific frequency ranges (Kryter 1985). Physical damage to a mammal's hearing apparatus can occur if it is exposed to sound impulses that have very high peak pressures, especially if they have very short rise times. (Rise time is the interval required for sound pressure to increase from the baseline pressure to peak pressure.)

There is no specific evidence that exposure to pulses of airgun sound can cause PTS in any marine mammal, even with large arrays of airguns. However, given the 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 (e.g., Richardson et al. 1995, p. 372*ff*; Gedamke et al. 2008). Single or occasional occurrences of mild TTS are not indicative of permanent auditory damage, but repeated or (in some cases) single exposures to a level well above that causing TTS onset might elicit PTS.

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; Southall et al. 2007). However, there is special concern about strong sounds whose pulses have very rapid rise times. In terrestrial mammals, there are situations when pulses with rapid rise times (e.g., from explosions) can result in PTS even though their peak levels are only a few dB higher than the level causing slight TTS. The rise time of airgun pulses is fast, but not as fast as that of an explosion.

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

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

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

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 M_{mf}-weighted TTS threshold, in a beluga, for a watergun impulse). Additional assumptions had to be made to derive a corresponding estimate for pinnipeds, as the only available data on TTS-thresholds in pinnipeds pertained to non-impulse sound (see above). Southall et al. (2007) estimated that the PTS threshold could be a cumulative M_{pw}-weighted SEL of ~186 dB re 1 $\mu Pa^2 \cdot s$ in the case of a harbor seal exposed to impulse sound. The PTS threshold for the California sea lion and northern elephant seal would probably be higher given the higher TTS thresholds in those species. Southall et al. (2007) also 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. Thus, PTS might be expected upon exposure of cetaceans to <u>either</u> SEL ≥198 dB re 1 $\mu Pa^2 \cdot s$ <u>or</u> peak pressure ≥230 dB re 1 μPa. Corresponding proposed dual criteria for pinnipeds (at least harbor seals) are ≥186 dB SEL and ≥ 218 dB peak pressure (Southall et al. 2007). These estimates are all first approximations, given the limited underlying data, assumptions, species differences, and evidence that the "equal energy" model is not be entirely correct.

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, expressed on an SEL basis, exposure to several strong seismic pulses that each have flat-weighted received levels near 205 dB_{rms} (190–195 dB SEL) could result in cumulative exposure of ~198 dB SEL (M_{mf}-weighted), and thus slight PTS in a small odontocete. However, the levels of successive pulses that will be received by a marine mammal that is below the surface as a seismic vessel approaches, passes and moves away will tend to increase gradually and then decrease gradually, with periodic decreases superimposed on this pattern when the animal comes to the surface to breathe. To estimate how close an odontocete's CPA distance would have to be for the cumulative SEL to exceed 198 dB SEL (M_{mf}-weighted), one would (as a minimum) need to allow for the sequence of distances at which airgun shots would occur, and for the dependence of received SEL on distance in the region of the seismic operation (e.g., Erbe and King 2009).

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

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

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

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

6.3 Strandings and Mortality

Marine mammals close to underwater detonations of high explosives can be killed or severely injured, and the auditory organs are especially susceptible to injury (Ketten et al. 1993; Ketten 1995). However, explosives are no longer used in marine waters for commercial seismic surveys or (with rare exceptions) for seismic research; they have been replaced by airguns and other non-explosive sources. Airgun pulses are less energetic and have slower rise times, and there is no specific evidence that they can cause serious injury, death, or stranding even in the case of large airgun arrays. However, the association of mass strandings of beaked whales with naval exercises and, in one case, a seismic survey (Malakoff 2002; Cox et al. 2006), has raised the possibility that beaked whales exposed to strong "pulsed" sounds may be especially susceptible to injury and/or behavioral reactions that can lead to stranding (e.g., Hildebrand 2005; Southall et al. 2007). Hildebrand (2005) reviewed the association of cetacean strandings with high-intensity sound events and found that deep-diving odontocetes, primarily beaked whales, were by far the predominant (95%) cetaceans associated with these events, with 2% mysticete whales (minke). However, as summarized below, there is no definitive evidence that airguns can lead to injury, strandings, or mortality even for marine mammals in close proximity to large airgun arrays.

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

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

There is no conclusive evidence of cetacean strandings or deaths at sea as a result of exposure to seismic surveys, 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, given its downward-directed beams, much shorter pulse durations, and lower duty cycle. Nonetheless, the Gulf of California incident plus the beaked whale strandings near naval exercises involving use of mid-frequency sonar suggest a need for caution in conducting seismic surveys in areas occupied by beaked whales until more is known about effects of seismic surveys on those species (Hildebrand 2005).

6.4 Non-Auditory Physiological Effects

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

Available data on potential stress-related impacts of anthropogenic noise on marine mammals are extremely limited, and additional research on this topic is needed. We know of only two specific studies of noise-induced stress in marine mammals. ***(1)*** Romano et al. (2004) examined the effects of single underwater impulse sounds from a seismic water gun (source level up to 228 dB re 1 µPa **@ 1**m_{p-p}) and single short-duration pure tones (sound pressure level up to 201 dB re 1 µPa) on the nervous and immune systems of a beluga and a bottlenose dolphin. They found that neural-immune changes to noise exposure were minimal. Although levels of some stress-released substances (e.g., catecholamines) changed significantly with exposure to sound, levels returned to baseline after 24 hr. ***(2)*** During playbacks of recorded drilling noise to four captive beluga whales, Thomas et al. (1990) found no changes in blood levels of stress-related hormones. Long-term effects were not measured, and no short-term effects were detected. For both studies, caution is necessary when extrapolating these results to wild animals and to real-world situations given the small sample sizes, use of captive animals, and other technical limitations of the two studies.

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

In summary, very little is known about the potential for seismic survey sounds (or other types of strong underwater sounds) to cause non-auditory physiological effects in marine mammals. Such effects, if they occur at all, would presumably be limited to short distances and to activities that extend over a prolonged period. The available data do not allow identification of a specific exposure level above which non-auditory effects can be expected (Southall et al. 2007), or any meaningful quantitative predictions of the numbers (if any) of marine mammals that might be affected in these ways.

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APPENDIX D:
REVIEW OF THE EFFECTS OF AIRGUN SOUNDS ON FISHES[8]

Here we review literature about the effects of airgun sounds on fishes during seismic surveys. The potential effect of seismic sounds on fish has been studied with a variety of taxa, including marine, freshwater, and anadromous species (reviewed by Fay and Popper 2000; Ladich and Popper 2004; Hastings and Popper 2005; Popper and Hastings 2009a,b).

It is sometimes difficult to interpret studies on the effects of underwater sound on marine animals because authors often do not provide enough information, including received sound levels, source sound levels, and specific characteristics of the sound. Specific characteristics of the sound include units and references, whether the sound is continuous or impulsive, and its frequency range. Underwater sound pressure levels are typically reported as a number of decibels referenced to a reference level, usually 1 micro-Pascal (µPa). However, the sound pressure dB number can represent multiple types of measurements, including "zero to peak", "peak to peak", or averaged ("rms"). Sound exposure levels (SEL) may also be reported as dB. The SEL is the integration of all the acoustic energy contained within a single sound event. Unless precise measurement types are reported, it can be impossible to directly compare results from two or more independent studies.

1. Acoustic Capabilities

Sensory systems – like those that allow for hearing – provide information about an animal's physical, biological, and social environments, in both air and water. 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) that provide information about their surroundings (Fay and Popper 2000). Fay (2009) and some others refer to the ambient sounds to which fishes are exposed as 'underwater soundscapes'. Anthropogenic sounds can have important negative consequences for fish survival and reproduction if they disrupt an individual's ability to sense its soundscape, which often tells of predation risk, prey items, or mating opportunities. Potential negative effects include masking of key environmental sounds or social signals, displacement of fish from their habitat, or interference with sensory orientation and navigation.

Fish hearing via the inner ear is typically restricted to low frequencies. As with other vertebrates, fish hearing involves a mechanism whereby the beds of hair cells (Howard et al. 1988; Hudspeth and Markin 1994) located in the inner ear are mechanically affected and cause a neural discharge (Popper and Fay 1999). At least two major pathways for sound transmittance between sound source and the inner ear have been identified for fishes. The most primitive pathway involves direct transmission to the inner ear's otolith, a calcium carbonate mass enveloped by sensory hairs. The inertial difference between the dense otolith and the less-dense inner ear causes the otolith to stimulate the surrounding sensory hair cells. This motion differential is interpreted by the central nervous system as sound.

The second transmission pathway between sound source and the inner ear of fishes is via the swim bladder, a gas-filled structure that is much less dense than the rest of the fish's body. The swim bladder, being more compressible and expandable than either water or fish tissue, will differentially contract and

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[8] By **John R. Christian and R.C. Bocking**, LGL Ltd., environmental research associates (rev. Dec. 2009)

expand relative to the rest of the fish in a sound field. The pulsating swim bladder transmits this mechanical disturbance directly to the inner ear (discussed below). Such a secondary source of sound detection may be more or less effective at stimulating the inner ear depending on the amplitude and frequency of the pulsation, and the distance and mechanical coupling between the swim bladder and the inner ear (Popper and Fay 1993).

Some fish species may only have the direct pathway to the inner ear (i.e., lack swim bladders, have reduced swim bladders, or have swim bladders that are not coupled to the inner ear) and tend to exhibit relatively poor auditory sensitivity. These species are known as *hearing generalists* (Popper and Fay 1999). Currently, most marine fishes, including cartilaginous fishes (e.g., sharks, skates, rays, and chimeras of the Class Chondrichthys), are classified as *hearing generalists*. Typically, these fishes are sensitive to underwater sounds with frequencies less than 1 kHz.

Herring-like fishes (Clupeiformes), some cod-like fishes (Gadiformes in part), some squirrelfishes (Perciform family Holocentridae, in part), and a number of other fishes have specialized swim bladders that are either attached to the inner ear (i.e., by a Weberian ossicle) or are in physical proximity to the inner ear. Fishes with these swim bladder modifications appear to have lower hearing thresholds and to be sensitive to a wider sound frequency range than fishes lacking such specialization (Blaxter 1981), and are thus called *hearing specialists*. The upper limit of the hearing frequency range of these fishes is about 4 kHz. Fishes of the anadromous herring subfamily Alosinae (the anadromous shads and near-shore menhadens) that have been studied to date respond to sound frequencies exceeding 100 kHz (Mann et al. 1997, 1998, 2001) and are sometimes referred to as *extreme hearing specialists*.

It is important to recognize that the swim bladder itself is not a sensory end organ, but rather an intermediate part of the sound pathway between sound source and the inner ear of some fishes. The inner ear of both *hearing specialists* and *hearing generalists* is ultimately the organ that translates the particle displacement component into neural signals for the brain to interpret as sound.

A third mechanosensory pathway found in most bony fishes and elasmobranchs (i.e., cartilaginous fishes) involves the lateral line system. It too relies on sensitivity to water particle motion. The basic sensory unit of the lateral line system is the neuromast, a bundle of sensory and supporting cells whose projecting cilia, similar to those in the ears, are encased in a gelatinous cap. Neuromasts detect distorted sound waves in the immediate vicinity of fishes. Generally, fishes use the lateral line system to detect the particle displacement component of low frequency acoustic signals (up to 160 to 200 Hz) over a distance of one to two body lengths. The lateral line is used in conjunction with other sensory systems, including hearing (Sand 1981; Coombs and Montgomery 1999).

2. Potential Effects on Fishes

Review papers on the effects of anthropogenic sources of underwater sound on fishes have been published recently (Popper 2009; Popper and Hastings 2009a,b). These papers consider various sources of anthropogenic sound, including seismic airguns. For the purposes of this review, only the effects of seismic airgun sound are considered.

2.1 Marine Fishes

Evidence for airgun-induced damage to fish ears has come from studies using pink snapper *Pagrus auratus* (McCauley et al. 2000a,b, 2003). In these experiments, fish were caged and exposed to the sound of a single moving seismic airgun every 10 s over a period of 1 h and 41 min. The source SPL at 1 m was about 223 dB re 1 $\mu Pa \cdot m_{p\text{-}p}$, and the received SPLs ranged from 165 to 209 dB re 1 $\mu Pa_{p\text{-}p}$. The sound energy was highest over the 20–70 Hz frequency range. The pink snapper were exposed to more than 600 airgun discharges during the study. In some individual fish, the sensory epithelium of the inner ear sustained extensive damage as indicated by ablated hair cells. Damage was more extensive in fish examined 58 days post-exposure compared to those examined 18 h post-exposure. There was no evidence of repair or replacement of damaged sensory cells up to 58 days post-exposure. McCauley et al. (2000a,b, 2003) included the following caveats in the study reports: (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) 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).

The fish exposed to sound from a single airgun in this study also exhibited startle responses to short range start up and high-level airgun signals (i.e., with received SPLs of 182 to 195 dB re 1 μPa_{rms} (McCauley et al. 2000a,b). Smaller fish were more likely to display a startle response. Responses were observed above received SPLs of 156 to 161 dB re 1 μPa_{rms}. The occurrence of both startle response (classic C-turn response) and alarm responses (e.g., darting movements, flash school expansion, fast swimming) decreased over time. Other 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.

Pearson et al. (1992) investigated the effects of seismic airgun sound on the behavior of captive rockfishes (*Sebastes* sp.) exposed to the sound of a single stationary airgun at a variety of distances. The airgun used in the study had a source SPL at 1 m of 223 dB re 1 $\mu Pa \cdot m_{0\text{-}p}$, and measured received SPLs ranged from 137 to 206 dB re 1 $\mu Pa_{0\text{-}p}$. The authors reported that rockfishes reacted to the airgun sounds by exhibiting varying degrees of startle and alarm responses, depending on the species of rockfish and the received SPL. Startle responses were observed at a minimum received SPL of 200 dB re 1 $\mu Pa_{0\text{-}p}$, and 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 fishes ascended in the water column and commenced to mill (i.e., "eddy") at increased speed, while others descended to the bottom of the enclosure and remained motionless. Pre-exposure behavior was reestablished from 20 to 60 min after cessation of seismic airgun discharge. Pearson et al. (1992) concluded that received SPL thresholds for overt 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.

Using an experimental hook and line fishery approach, Skalski et al. (1992) studied the potential effects of seismic airgun sound on the distribution and catchability of rockfishes. The source SPL of the single airgun used in the study was 223 dB re 1 $\mu Pa \cdot m_{0\text{-}p}$, and the received SPLs at the bases of the rockfish aggregations ranged from 186 to 191 dB re 1 $\mu Pa_{0\text{-}p}$. Characteristics of the fish aggregations were assessed using echosounders. During long-term stationary seismic airgun discharge, there was an overall downward shift in fish distribution. The authors also observed a significant decline in total catch of rockfishes during seismic discharge. It should be noted that this experimental approach was quite different from an actual seismic survey, in that duration of exposure was much longer.

In another study, caged European sea bass (*Dicentrarchus labrax*) were exposed to multiple discharges from a moving seismic airgun array with a source SPL of about 256 dB re 1 $\mu Pa \cdot m_{0\text{-}p}$ (unspecified measure type) (Santulli et al. 1999). The airguns were discharged every 25 s during a 2-h 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 h post-exposure) and control fish (6 h pre-exposure) and subsequently analyzed for cortisol, glucose, and lactate levels. Levels of cortisol, glucose, and lactate were significantly higher in the sera of exposed fish compared to sera of control fish. The elevated levels of all three chemicals returned to pre-exposure levels within 72 h of exposure (Santulli et al. 1999).

Santulli et al. (1999) also used underwater video cameras to monitor fish response to seismic airgun discharge. Resultant video indicated slight startle responses by some of the sea bass when the seismic airgun array discharged as far as 2.5 km from the cage. The proportion of sea bass that exhibited startle response increased as the airgun sound source approached the cage. Once the seismic array was within 180 m of the cage, the sea bass were densely packed at the middle of the enclosure, exhibiting random orientation, and appearing more active than they had been under pre-exposure conditions. Normal behavior resumed about 2 h after airgun discharge nearest the fish (Santulli et al. 1999).

Boeger et al. (2006) reported observations of coral reef fishes in field enclosures before, during and after exposure to seismic airgun sound. This Brazilian study used an array of eight airguns that was presented to the fishes as both a mobile sound source and a static sound source. Minimum distances between the sound source and the fish cage ranged from 0 to 7 m. Received sound levels were not reported by Boeger et al. (2006). Neither mortality nor external damage to the fishes was observed in any of the experimental scenarios. Most of the airgun array discharges resulted in startle responses although these behavioral changes lessened with repeated exposures, suggesting habituation.

Chapman and Hawkins (1969) investigated the reactions of free ranging whiting (silver hake), *Merluccius bilinearis*, to an intermittently discharging stationary airgun with a source SPL of 220 dB re 1 μPa·m$_{0-p}$. Received SPLs were estimated to be 178 dB re 1 μPa$_{0-p}$. The whiting were monitored with an echosounder. Prior to any airgun discharge, the fish were located at a depth range of 25 to 55 m. In apparent response to the airgun sound, the fish descended, forming a compact layer at depths greater than 55 m. After an hour of exposure to the airgun sound, the fish appeared to have habituated as indicated by their return to the pre-exposure depth range, despite the continuing airgun discharge. Airgun discharge ceased for a time and upon its resumption, the fish again descended to greater depths, indicating only temporary habituation.

Hassel et al. (2003, 2004) studied the potential effects of exposure to airgun sound on the behavior of captive lesser sandeel, *Ammodytes marinus*. Depth of the study enclosure used to hold the sandeel was about 55 m. The moving airgun array had an estimated source SPL of 256 dB re 1 μPa @ 1m (unspecified measure type). Received SPLs were not measured. Exposures were conducted over a 3-day period in a 10 km × 10 km area with the cage at its center. The distance between airgun array and fish cage ranged from 55 m when the array was overhead to 7.5 km. No mortality attributable to exposure to the airgun sound was noted. Behavior of the fish was monitored using underwater video cameras, echo-sounders, and commercial fishery data collected close 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 airgun discharge, 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 airgun discharge ceased. The sandeel tended to remain higher in the water column during the airgun discharge, and none of them were observed burying themselves in the soft substrate. The commercial fishery catch data were inconclusive with respect to behavioral effects.

Various species of demersal fishes, blue whiting, and some small pelagic fishes were exposed to a moving seismic airgun array with a source SPL of about 250 dB re 1 µPa **@ 1** 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). Seismic sound exposures were conducted every 10 s during a one week period. The authors used echosounders and sonars to assess the pre- and post-exposure fish distributions. The acoustic mapping results indicated a significant decrease in abundance of demersal fish (36%) after airgun discharge but comparative trawl catches did not support this. Non-significant reductions in the abundances of blue whiting and small pelagic fish were also indicated by post-exposure acoustic mapping.

La Bella et al. (1996) studied the effects of exposure to seismic airgun sound on fish distribution using echosounder monitoring and changes in catch rate of hake by trawl, and clupeoids by gill netting. The seismic array used was composed of 16 airguns and had a source SPL of 256 dB re 1 µPa ·m$_{0\text{-}p}$ The shot interval was 25 s, and exposure durations ranged from 4.6 to 12 h. Horizontal distributions did not appear to change as a result of exposure to seismic discharge, but there was some indication of a downward shift in the vertical distribution. The catch rates during experimental fishing did not differ significantly between pre- and post-seismic fishing periods.

Wardle et al. (2001) used video and telemetry to make behavioral observations of marine fishes (primarily juvenile saithe, adult pollock, juvenile cod, and adult mackerel) inhabiting an inshore reef off Scotland before, during, and after exposure to discharges of a stationary airgun. The received SPLs ranged from about 195 to 218 dB re 1 µPa$_{0\text{-}p}$. Pollock did not move away from the reef in response to the seismic airgun sound, and their diurnal rhythm did not appear to be affected. However, there was an indication of a slight 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. There were also indications of behavioral responses to visual stimuli. If the seismic source was visible to the fish, they fled from it. However, if the source was not visible to the fish, they often continued to move toward it.

The potential effects of exposure to seismic sound on fish abundance and distribution were also investigated by Slotte et al. (2004). Twelve days of seismic survey operations spread over a period of 1 month used a seismic airgun array with a source SPL of 222.6 dB re 1 µPa·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 horizontal distributional effects. With respect to vertical distribution, blue whiting and mesopelagics were distributed deeper (20 to 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.

Fertilized capelin (*Mallotus villosus*) eggs and monkfish (*Lophius americanus*) larvae were exposed to seismic airgun sound and subsequently examined and monitored for possible effects of the exposure (Payne et al. 2009). The laboratory exposure studies involved a single airgun. Approximate received SPLs measured in the capelin egg and monkfish larvae exposures were 199 to 205 dB re 1 µPa$_{p\text{-}p}$ and 205 dB re 1 µPa$_{p\text{-}p}$, respectively. The capelin eggs were exposed to either 10 or 20 airgun discharges, and the monkfish larvae were exposed to either 10 or 30 discharges. No statistical differences in mortality/morbidity between control and exposed subjects were found at 1 to 4 days post-exposure in any of the exposure trials for either the capelin eggs or the monkfish larvae.

In uncontrolled experiments, Kostyvchenko (1973) exposed the eggs of numerous fish species (anchovy, red mullet, crucian carp, blue runner) to various sound sources, including seismic airguns. With the seismic airgun discharge as close as 0.5 m from the eggs, over 75% of them survived the exposure. Egg survival rate increased to over 90% when placed 10 m from the airgun sound source. The range of received SPLs was about 215 to 233 dB re 1 $\mu Pa_{0\text{-}p}$.

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 to 6 m. The authors reported some cases of injury and mortality but most of these occurred as a result of exposures at very close range (i.e., <15 m). The rigor of anatomical and pathological assessments was questionable.

Saetre and Ona (1996) applied a "worst-case scenario" mathematical model to investigate the effects of seismic sound on fish eggs and larvae. They concluded that mortality rates caused by exposure to seismic airgun sound 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.

2.2 Freshwater Fishes

Popper et al. (2005) tested the hearing sensitivity of three Mackenzie River fish species after exposure to five discharges from a seismic airgun. The mean received peak SPL was 205 to 209 dB re 1 µPa per discharge, and the approximate mean received SEL was 176 to 180 dB re 1 $\mu Pa^2 \cdot s$ per discharge. While the broad whitefish showed no Temporary Threshold Shift (TTS) as a result of the exposure, adult northern pike (a *hearing generalist*), and lake chub (*hearing specialist*) exhibited TTSs of 10 to 15 dB, followed by complete recovery within 24 h of exposure. The same animals were also examined to determine whether there were observable effects on the sensory cells of the inner ear as a result of exposure to seismic sound (Song et al. 2008). No damage to the ears of the fishes was found, including those that exhibited TTS.

In another part of the same Mackenzie River project, Jorgenson and Gyselman (2009) investigated the behavioral responses of arctic riverine fishes to seismic airgun sound. They used hydroacoustic survey techniques to determine whether fish behavior upon exposure to airgun sound can either mitigate or enhance the potential impact of the sound. The study indicated that fish behavioral characteristics were generally unchanged by the exposure to airgun sound. The tracked fish did not exhibit herding behavior in front of the mobile airgun array and, therefore, were not exposed to sustained high sound levels.

2.3 Anadromous Fishes

In uncontrolled experiments using 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 to 15 s apart of a 300-in^3 seismic airgun at 2000 to 2200 psi (Falk and Lawrence 1973). Swim bladder damage was reported but no mortality was observed when fish were exposed within 1 to 2 m of an airgun source with source level, as estimated by Turnpenny and Nedwell (1994), of ~230 dB re 1 µPa **@ 1**m (unspecified measure).

Thomsen (2002) exposed rainbow trout and Atlantic salmon held in aquaculture enclosures to the sounds from a small airgun array. Received SPLs were 142 to 186 dB re 1 $\mu Pa_{p\text{-}p}$. 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. Only eight of the 124 shots appeared to evoke behavioral reactions by the salmonids, but overall impacts were minimal. No fish mortality was observed during or 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 at distances ranging from 1 to 10 m, resulting in received levels estimated at ~214 to 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 above for problems with experimental design and execution, measurements, and interpretation. Hastings and Popper (2005) deal primarily with possible effects of pile-driving sounds (which, like airgun sounds, are impulsive and repetitive). However, that review provides an excellent and critical review of the impacts to fish from other underwater anthropogenic sounds.

3. Indirect Effects on Fisheries

The most comprehensive experimentation on the effects of seismic airgun sound on catchability of fishes was conducted in the Barents Sea by Engås et al. (1993, 1996). They investigated the effects of seismic airgun sound on distributions, abundances, and catch rates of cod and haddock using acoustic mapping and experimental fishing with trawls and longlines. The maximum source SPL was about 248 dB re 1 µPa·m $_{0\text{-p}}$ based on back-calculations from measurements collected via a hydrophone at depth 80 m. Nomeasurements of the received SPLs were made. Davis et al. (1998) estimated the received SPL at the sea bottom immediately below the array and at 18 km from the array to be 205 dB re 1 µPa$_{0\text{-p}}$ and 178 dB re 1 µPa$_{0\text{-p}}$, respectively. Engås et al. (1993, 1996) concluded that there were indications of distributional change during and immediately following the seismic airgun discharge (45 to 64% decrease in acoustic density according to sonar data). The lowest densities were observed within 9.3 km of the seismic discharge area. The authors indicated that trawl catches of both cod and haddock declined after the seismic operations. While longline catches of haddock also showed decline after seismic airgun discharge, those for cod increased.

Løkkeborg (1991), Løkkeborg and Soldal (1993), and Dalen and Knutsen (1986) also examined the effects of seismic airgun sound on demersal fish catches. Løkkeborg (1991) examined the effects on cod catches. The source SPL of the airgun array used in his study was 239 dB re 1 µPa·m (unspecified measure type), but received SPLs were not measured. Approximately 43 h of seismic airgun discharge occurred during an 11-day period, with a five-second interval between pulses. Catch rate decreases ranging from 55 to 80% within the seismic survey area were observed. This apparent effect persisted for at least 24 h within about 10 km of the survey area.

Turnpenny et al. (1994) examined results of these studies as well as the results of other studies on rockfish. They used rough estimations of received SPLs at catch locations and concluded that catchability is reduced when received SPLs exceed 160 to 180 dB re 1 µPa$_{0\text{-p}}$. They also concluded that reaction thresholds of fishes lacking a swim bladder (e.g., flatfish) would likely be about 20 dB higher. Given the considerable variability in sound transmission loss between different geographic locations, the SPLs that were assumed in these studies were likely quite inaccurate.

Turnpenny and Nedwell (1994) also reported on the effects of seismic airgun discharge on inshore bass fisheries in shallow U.K. waters (5 to 30 m deep). The airgun array used had a source level of 250 dB re 1 µPa·m$_{0\text{-p}}$. Received levels in the fishing areas were estimated to be 163–191 dB re 1 µPa$_{0\text{-p}}$.

Using fish tagging and catch record methodologies, they concluded that there was not any distinguishable migration from the ensonified area, nor was there any reduction in bass catches on days when seismic airguns were discharged. The authors 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.

Skalski et al. (1992) used a 100-in^3 airgun with a source level of 223 dB re 1 µPa·m$_{0\text{-}p}$ to examine the potential effects of airgun sound on the catchability of rockfishes. The moving airgun was discharged along transects in the study fishing area, after which a fishing vessel deployed a set line, ran three echo-sounder transects, and then deployed two more set lines. Each fishing experiment lasted 1 h 25 min. Received SPLs at the base of the rockfish aggregations ranged from 186 to 191 dB re 1 µPa$_{0\text{-}p}$. The catch-per-unit-effort (CPUE) for rockfish declined on average by 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 fishes. The fish schools descended towards the bottom and their swimming behavior changed during airgun discharge. Although fish dispersal was not observed, the authors hypothesized that it could have occurred at a different location with a different bottom type. Skalski et al. (1992) did not continue fishing after cessation of airgun discharge. They speculated that CPUE would quickly return to normal in the experimental area, because fish behavior appeared to normalize within minutes of cessation of airgun discharge. However, in an area where exposure to airgun sound might have caused the fish to disperse, the authors suggested that a lower CPUE might persist for a longer period.

European sea bass were exposed to sound from seismic airgun arrays with a source SPL of 262 dB re 1 µPa·m$_{0\text{-}p}$ (Pickett et al. 1994). The seismic survey was conducted over a period of 4 to 5 months. The study was intended to investigate the effects of seismic airgun discharge 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 a prolonged period. With respect to the commercial fishery, no significant changes in catch rate were observed (Pickett et al. 1994).

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