Request by the University of Texas to Allow the Incidental Harassment of Marine Mammals During a Marine Geophysical Survey of the Western Canada Basin, Chukchi Borderland and Mendeleev Ridge, Arctic Ocean, July–August 2006

submitted by

University of Texas at Austin Institute for Geophysics
4412 Spicewood Springs Road #600
Austin, TX 78759-8500

to

National Marine Fisheries Service
Office of Protected Resources
1315 East–West Hwy, Silver Spring, MD 20910-3282

Application prepared by

LGL Alaska Research Associates, Inc.
1101 East 76th Ave., Suite B; Anchorage, AK 99518

and

LGL Ltd., environmental research associates
22 Fisher St., POB 280, King City, Ont. L7B 1A6

1 March 2006

LGL Report TA4285-2

TABLE OF CONTENTS

Request by the University of Texas for an Incidental Harassment Authorization to Allow the Incidental Harassment of Marine Mammals During a Marine Geophysical Survey of the Western Canada Basin, Chukchi Borderland and Mendeleev Ridge, Arctic Ocean, July–August 2006

SUMMARY

The University of Texas at Austin Institute for Geophysics (UTIG), with research funding from the National Science Foundation (NSF), plans to conduct a marine seismic survey of the Western Canada Basin, Chukchi Borderland and Mendeleev Ridge of the Arctic Ocean during the period 15 July to 25 August 2006 (approximately). UTIG requests that it be issued an Incidental Harassment Authorization (IHA) allowing non-lethal takes of marine mammals incidental to the planned seismic survey in the Arctic Ocean. This request is submitted pursuant to Section 101 (a) (5) (D) of the Marine Mammal Protection Act (MMPA), 16 U.S.C. § 1371 (a) (5). Portions of the seismic survey will be conducted in the Exclusive Economic Zones (EEZs) of the U.S.A.

Several species of cetaceans and pinnipeds inhabit the Arctic Ocean. 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 most likely to occur within the survey area. The survey has been scheduled specifically to avoid the spring and fall bowhead whale migrations north of Barrow. UTIG is proposing a marine mammal monitoring and mitigation program to minimize the impacts of the proposed activity on marine mammals present during conduct of the proposed research, and to document the nature and extent of any effects.

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

I. OPERATIONS TO BE CONDUCTED

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

Overview of the Activity

The University of Texas at Austin Institute for Geophysics (UTIG), with research funding from the National Science Foundation (NSF), plans to conduct a marine seismic survey in the Western Canada Basin, Chukchi Borderland and Mendeleev Ridge of the Arctic Ocean (Fig. 1), for ~40 days during the period 15 July to 25 August 2006. Some variation in these dates is possible, given the uncertainties in ice and other factors. The seismic survey will be operated in conjunction with a sediment coring project, which will obtain data regarding crustal structure.

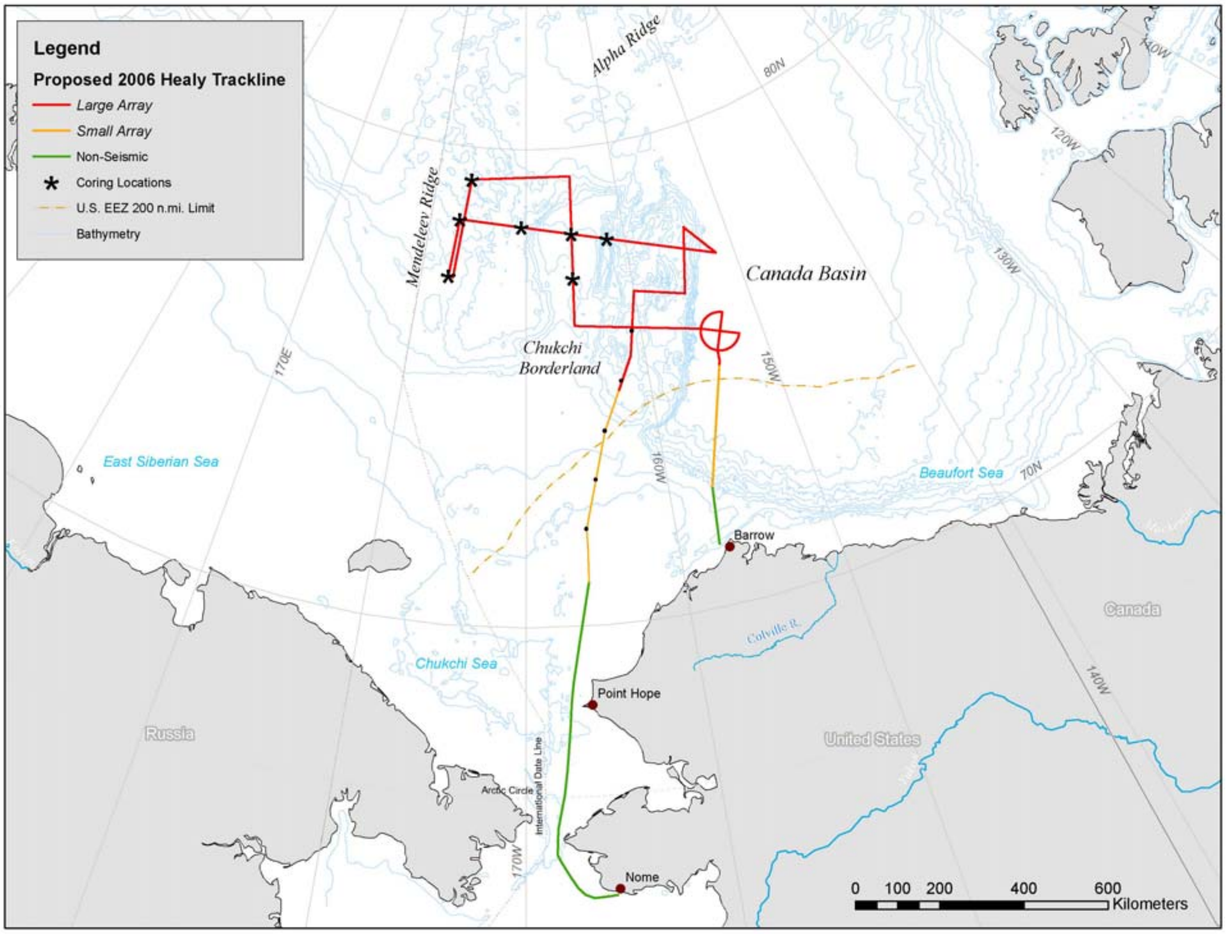


FIGURE 1. Proposed location of UTIG's July–August 2006 Arctic Ocean seismic survey lines and coring areas. The precise track may vary somewhat from this nominal version depending on ice conditions.

The purpose of the proposed study is to collect seismic reflection and refraction data and sediment cores that reveal the crustal structure and composition of submarine plateaus in the western Amerasia Basin in the Arctic Ocean. Past studies have led many researchers to support the idea that the Amerasia Basin opened about a pivot point near the Mackenzie Delta. However, the crustal character of the Chukchi Borderlands could determine whether that scenario is correct, or whether more complicated tectonic scenarios must be devised to explain the presence of the Amerasia Basin. These data will assist in the determination of the tectonic evolution of the Amerasia Basin and Canada Basin which is fundamental to such basic concerns as sea level fluctuations and paleoclimate in the Mesozoic era.

The geophysical survey will involve the United States Coast Guard (USCG) cutter *Healy*, a USCG icebreaker, which will begin the seismic survey >150 km (81 n.mi) off the coast of Barrow, Alaska. The *Healy* will use a portable Multi-Channel Seismic (MCS) system to conduct the seismic survey. A cluster of eight airguns will be used as the energy source during most of the cruise, especially in deep water areas. The airgun array will have four 500 in^3 Bolt airguns and four 210 in^3 G. guns for a total discharge volume of 2840 in^3. In shallow water, occurring during the first and last portions of the cruise, a four 105 in^3 GI gun array with a total discharge volume of 420 in^3 will be used. Other sound sources (see below) will also be employed during the cruise. The seismic operations during the survey will be used to obtain information on the history of the ridges and basins that make up the Arctic Ocean.

The airgun arrays will discharge about once every 60 s. The compressed air will be supplied by compressors on board the source vessel. The *Healy* will also tow a hydrophone streamer 100–150 m behind the ship, depending on ice conditions. The hydrophone streamer will be up to 200 m long. As the source operates along the survey lines, the hydrophone receiving system will receive and record the returning acoustic signals. In addition to the hydrophone streamer, sea ice seismometers (SIS) will be deployed on ice floes ahead of the ship using a vessel-based helicopter, and then retrieved from behind the ship once it has passed the SIS locations. SISs will be deployed as much as 120 km ahead of the ship, and recovered when as much as 120 km behind the ship. The seismometers will be placed on top of ice floes with a hydrophone lowered into the water through a small hole drilled in the ice. These instruments will allow seismic refraction data to be collected in the heavily ice-covered waters of the region.

The program will consist of a total of ~3625 km of surveys, not including transits when the airguns are not operating, plus scientific coring at (at least) seven locations (Fig. 1). Water depths within the study area are 40–3858 m. Little more than 8% of the survey (~300 km) will occur in water depths <100 m, 23% of the survey (~838 km) will be conducted in water 100–1000 m deep, and most (69%) of the survey (~2486 km) will occur in water deeper than 1000 m. There will be additional seismic operations associated with airgun testing, start up, and repeat coverage of any areas where initial data quality is sub-standard. In addition to the airgun array, a multibeam sonar and sub-bottom profiler will be used during the seismic profiling and continuously when underway. A pinger may be used during coring to help direct the core bit.

This is an NSF-funded research effort that includes seismic activities and scientific coring by scientists from UTIG and the United States Geological Survey (USGS). The chief scientists are Dr. Lawrence Lawver and Dr. Harm van Avendonk of UTIG and Dr. Art Grantz of the USGS. The vessel will be self-contained, and the crew will live aboard the vessel for the entire cruise.

The coring operations (Table 1) will be conducted in conjunction with the seismic study from the *Healy*. Seismic operations will be suspended while the USCG *Healy* is on site for coring at each of (at least) seven locations. Several more coring sites may be identified and sampled depending on the ability to deploy SISs given ice and weather conditions. The plan is to extract one core from six of the seven identified sample locations along the seismic survey, and two cores at the last site on the Chukchi Cap (Table 1). The coring system to be used is a piston corer that is lowered to the sea floor via a deep sea winch. Coring is expected to occur in 400–4000 m water depths. The piston corer recovers a sample in PVC tubes of 10 cm in diameter. Most of the cores will be ~5–10 m long; maximum possible length will be ~24 m. The core is designed to leave nothing in the ocean after recovery.

Vessel Specifications

The *Healy* has a length of 128 m, a beam of 25 m, and a full load draft of 8.9 m (Fig. 2). The *Healy* is a USCG icebreaker, capable of traveling at 5.6 km/h (3 knots) through 1.4 m of ice. A "Central Power Plant", four Sultzer 12Z AU40S diesel generators, provides electric power for propulsion and ship's services through a 60 Hz, 3-phase common bus distribution system. Propulsion power is provided by two electric AC Synchronous, 11.2 MW drive motors, fed from the common bus through a Cycloconverter system, that turn two fixed-pitch, four-bladed propellers. The operation speed during seismic acquisition is expected to be ~6.5 km/h (3.5 knots). When not towing seismic survey gear or breaking ice, the *Healy* cruises at 22 km/h (12 knots) and has a maximum speed of 31.5 km/h (17 knots). She has a normal operating range of about 29,650 km (16,000 n.mi) at 23.2 km/hr (12.5 knots).

TABLE 1. Coring locations and approximate number of cores to be conducted at each site.

Coring Location	Location	Number of Cores
Mendeleev Ridge	77.2°N; 177.4°W	1
Mendeleev Ridge	78.5°N; 177.0°W	1
Mendeleev Ridge	79.3°N; 176.2°W	1
Chukchi Basin	78.4°N;170.5°W	1
Chukchi Cap	78.2°N; 165.3°W	1
Chukchi Cap	77.2°N; 165.5°W	1
Chukchi Cap	78.0°N; 161.8°E	2

Figure 2. The source vessel, the U.S. Coast Guard Cutter *Healy*, to be used during the proposed July-August Arctic Ocean seismic survey. Photograph from USCG *Healy* website at http://www.uscg.mil/pacarea/healy/.

The *Healy* will also serve as the platform from which vessel-based marine mammal observers will watch for marine mammals before and during airgun operations. The characteristics of the *Healy* that make it suitable for visual monitoring are described in § XIII, MONITORING AND REPORTING PLAN.

Other details of the *Healy* include the following:

Owner:	USCG
Operator:	USCG
Flag:	United States of America
Launch Date:	15 November 1997
Gross Tonnage:	16,000 LT
Bathymetric Survey Systems:	Seabeam 2112 Bottom Mapping Sonar, Knudsen 320 B/R Sub Bottom Profiler
Compressors for Air Guns:	2 portable compressors, capacity of 3964 L/min
Accommodation Capacity:	138 including ~50 scientists

Airgun Description and Safety Radii

A portable MCS system will be installed on the *Healy* for this cruise. The source vessel will tow along predetermined lines one of two different airgun arrays (an 8-airgun array with a total discharge volume of 2840 in^3 or a four GI gun array with a total discharge volume of 420 in^3), as well as a hydrophone streamer. Seismic pulses will be emitted at intervals of ~60 s and recorded at a 2 ms sampling rate. The 60 s spacing corresponds to a shot interval of ~120 m at the anticipated typical cruise speed.

As the airgun array is towed along the survey line, the towed hydrophone array receives the reflected signals and transfers the data to the on-board processing system. The SISs will store returning signals on an internal datalogger and also relay them in real-time to the *Healy* via a radio transmitter, where they will be recorded and processed.

The 8-airgun array will be configured as a four G. gun cluster with a total discharge volume of 840 in^3 and a four Bolt airgun cluster with a total discharge volume of 2000 in^3 (Fig. 3). The two clusters are four meters apart. The clusters will be operated simultaneously for a total discharge volume of 2840 in^3. The 4-GI gun array will be configured the same as the four G. gun portion of the 8-airgun array. The energy source will be towed as close to the stern as possible to minimize ice interference. The 8-airgun array will be towed below a depressor bird at a depth of 7–20 m depending on ice conditions; the preferred depth is 8–10 m. The specifications for the airgun array are shown below.

The highest sound level measurable at any location in the water from the airgun arrays would be slightly less than the nominal source level because the actual source is a distributed source rather than a point source. The depth at which the source is towed has a major impact on the maximum near-field output, and on the shape of its frequency spectrum. In this case, the source is expected to be towed at a relatively deep depth of up to 9 m.

The rms (root mean square) received levels that are used as impact criteria for marine mammals are not directly comparable to the peak or peak-to-peak values normally used to characterize source levels of airguns. The measurement units used to describe airgun sources, peak or peak-to-peak dB, are always higher than the rms dB referred to in much of the biological literature. A measured received level of 160 dB rms in the far field would typically correspond to a peak measurement of about 170 to 172 dB, and to a peak-to-peak measurement of about 176 to 178 decibels, *as measured for the same pulse received at the same location* (Greene 1997; McCauley et al. 1998, 2000). The precise difference between rms and peak or peak-to-peak values for a given pulse depends on the frequency content and duration of the pulse, among other factors. However, the rms level is always lower than the peak or peak-to-peak level for an airgun-type source. Additional discussion of the characteristics of airgun pulses is included in Appendix A.

4-GI gun Array Specifications

Energy source	Four GI guns of 105 in^3 generator - 105 in^3 injector firing every 60 s
Source output (downward)[1]	0-pk is 8.5 bar-m (239 dB re 1 μPa-m); pk-pk is 17.5 bar-m (245 dB)
Towing depth of energy source	~6 m
Air discharge volume	420 in^3
Dominant frequency components	0–150 Hz

8-airgun Array Specifications

Energy source	Four G. guns of 210 in^3 each, and four Bolt airguns of 500 in^3 each, firing simultaneously every 60 s
Source output (downward)[2]	0-pk is 20.3 bar-m (246 dB re 1 μPa-m); pk-pk is 42.5 bar-m (253 dB)
Towing depth of energy source	~9 m
Air discharge volume	2840 in^3
Dominant frequency components	0–150 Hz

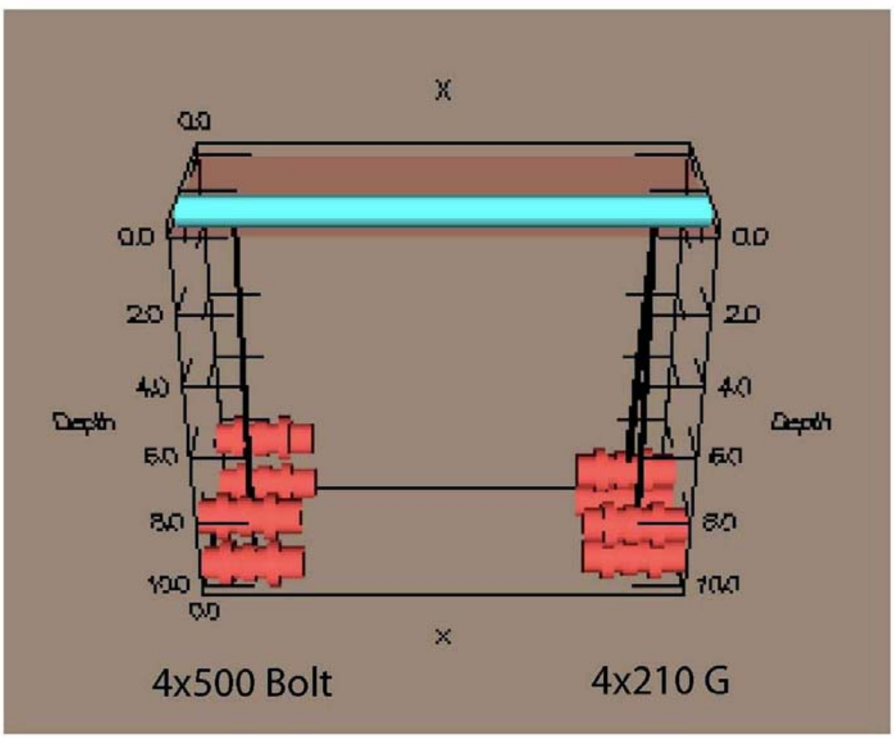


Figure 3. The spacing and configuration of the 8-airgun array to be towed behind the *Healy* during the proposed Arctic Ocean Survey, 15 July–25 August 2006. The four 105 in^3 GI gun array will be configured in the same manner as the 4 x 210 in^3 G. guns shown above on the right hand side of the figure. Measurements are in meters.

[1] All source levels are for a filter bandwidth of approximately 0-150 Hz.

Received sound fields have been modeled by Lamont-Doherty Earth Observatory (L-DEO) for the 8-airgun and 4-GI gun arrays that will be used during this survey (Figs. 4 and 5, respectively). For deep water, where most of the present project is to occur, the L-DEO model has been shown to be precautionary, i.e., it tends to overestimate radii for 190, 180, etc., dB re 1 μPa rms (Tolstoy et al. 2004a,b). Based on the model, the distances from various planned sources where sound levels of 190, 180, 170, and 160 dB re 1 μPa (rms) are predicted to be received are shown in the >1000 m lines of Table 2. Predicted sound fields were modeled using sound exposure level (SEL) units, i.e., dB re 1 μPa^2-s, because a model based on those units tends to produce more stable output when dealing with mixed-gun arrays like the one to be used during this survey. The predicted SEL values can be converted to rms received pressure levels, in dB re 1 μPa (as used in NMFS' impact criteria for pulsed sounds) by adding ~15 dB to the SEL value (Greene 1997; McCauley et al. 1998, 2000). The rms pressure is an average over the pulse duration. This is the measure commonly used in studies of marine mammal reactions to airgun sounds, and in NMFS guidelines concerning levels above which "taking" might occur. The rms level of a seismic pulse is typically about 10 dB less than its peak level.

Empirical data concerning 190, 180, 170, and 160 dB (rms) distances in deep and shallow water were acquired for various airgun array configurations during the acoustic verification study conducted by L-DEO in the northern Gulf of Mexico (Tolstoy et al. 2004a,b). Those were the data demonstrating that L-DEO's model tends to overestimate the distances applied in deep water. The proposed study area will occur mainly in water ~40–3858 m deep, with only ~8% of the survey lines in shallow (<100 m) water and ~23% of the trackline in intermediate water depths (100–1000 m). The calibration-study results showed that radii around the airguns where the received level would be 180 dB re 1 μPa (rms), the safety criterion applicable to cetaceans (NMFS 2000), vary with water depth. Similar depth-related variation is likely in the 190 dB distances applicable to pinnipeds.

The L-DEO model does not allow for bottom interactions, and thus is most directly applicable to deep water and to relatively short ranges. In intermediate-depth water a precautionary 1.5× factor will be applied to the values predicted by L-DEO's model, as has been done in other recent NSF-sponsored seismic studies. In shallow water, larger precautionary factors derived from the empirical shallow-water measurements will be applied (see Table 2).

- The empirical data indicate that, for ***deep water*** (>1000 m), the L-DEO model tends to overestimate the received sound levels at a given distance (Tolstoy et al. 2004a,b). However, to be precautionary pending acquisition of additional empirical data, it is proposed that safety radii during airgun operations in deep water will be the values predicted by L-DEO's modeling, after conversion from SEL to rms (Table 2). The estimated 190 and 180 dB (rms) radii for 8-airgun array are 230 and 716 m, respectively.
- Empirical measurements were not conducted for ***intermediate depths*** (100–1000 m). On the expectation that results would be intermediate between those from shallow and deep water, a 1.5× correction factor is applied to the estimates provided by the model for deep water situations. This is the same factor that has been applied to the model estimates during NSF-sponsored seismic operations in intermediate-depth water from 2003 through 2005. The assumed 190 and 180 dB (rms) radii in intermediate-depth water are 345 m and 1074 m, respectively, for the 8-airgun array (Table 2).

TABLE 2. Estimated distances to which sound levels ≥190, 180, 170, and 160 dB re 1 µPa (rms) might be received from a single 105 in^3 GI gun, one 210 in^3 G. gun, a 420 in^3 4-GI gun array, and an 8-gun array (4 x 500 in^3 Bolt airguns and 4 x 210 in^3 G. guns) that will be used during the seismic survey in the Arctic Ocean during 2006. The sound radii used during the survey will depend on water depth (see text). Distances are based on model results provided by L-DEO, supplemented by results of Tolstoy et al (2004a,b).

Seismic Source Volume	Water depth	Estimated Distances for Received Levels (m)			
		190 dB (shut-down criterion for pinnipeds)	**180 dB** (shut-down criterion for cetaceans)	**170 dB** (alternate behavioral harassment criterion for delphinids & pinnipeds)	**160 dB** (assumed onset of behavioral harassment)
105 in^3 GI gun	>1000 m	10	27	90	275
	100–1000 m	15	41	135	413
	<100 m	125	200	375	750
210 in^3 G. gun	>1000 m	20	78	222	698
	100–1000 m	30	117	333	1047
	<100 m	250	578	925	1904
420 in^3 (4-GI gun array)	>1000 m	75	246	771	2441
	100–1000 m	113	369	1157	3662
	<100 m	938	1822	3213	6657
2840 in^3 (8-airgun array)	>1000 m	230	716	2268	7097
	100–1000 m	345	1074	3402	10646
	<100 m	NA*	NA*	NA*	NA*

*The 8-airgun array will not be operated in shallow (<100 m) water during the survey.

- Empirical measurements were not made for the 4 GI guns that will be employed during the proposed survey in shallow water (<100 m). (The 8-airgun array will not be used in **shallow water**.) The empirical data on operations of two 105 in^3 GI guns in shallow water showed that modeled values underestimated the distance to the actual 160 dB sound level radii in shallow water by a factor of ~3 (Tolstoy et al. 2004b). Sound level measurements for the 2 GI guns were not available for distances <0.5 km from the source. The radii estimated here for the 4 GI guns operating in shallow water are derived from the L-DEO model, with the same adjustments for depth-related differences between modeled and measured sound levels as were used for 2 GI guns in earlier applications. Correction factors for the different sound level radii are ~12x the model estimate for the 190 dB radius in shallow water, ~7x for the 180 dB radius-and ~4x for the 170 dB radius [Tolstoy 2004a,b]). Thus, the 190 and 180 dB radii in shallow water are assumed to be 938 m and 1822 m, respectively for the 4-GI gun array (Table 2).

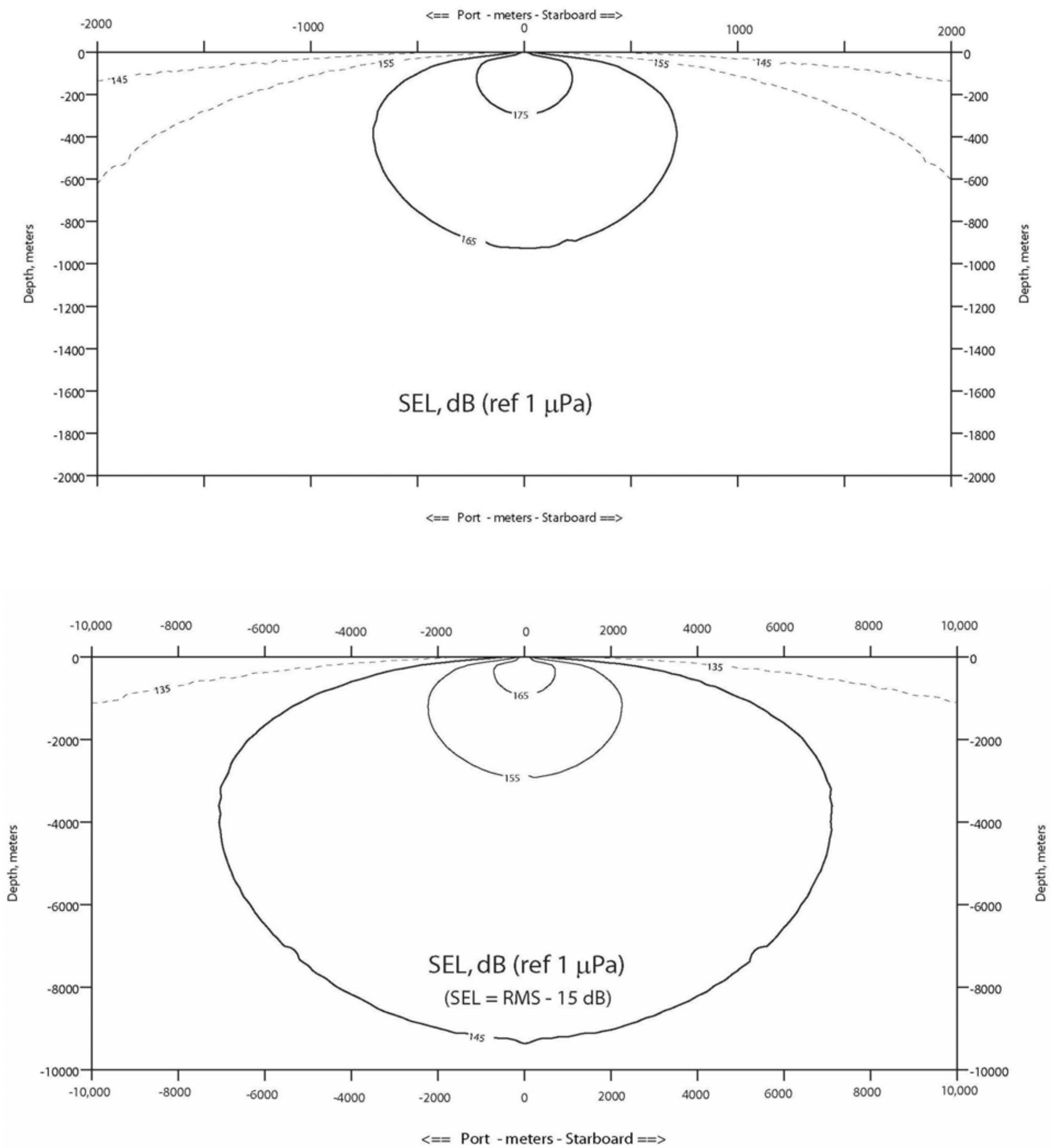


FIGURE 4. Modeled received sound levels from the 8-airgun array (4 x 500 in^3 Bolt airguns and 4 x 210 in^3 G. guns) that will be used during the UTIG survey in the Arctic Ocean during 2006, assuming an operating depth of 9 m. The model does not allow for bottom interactions, so is most directly applicable to deep-water situations. Model results are provided by L-DEO. The two panels show the same predicted values, with the top panel being an enlargement of the near-source portion of the bottom panel.

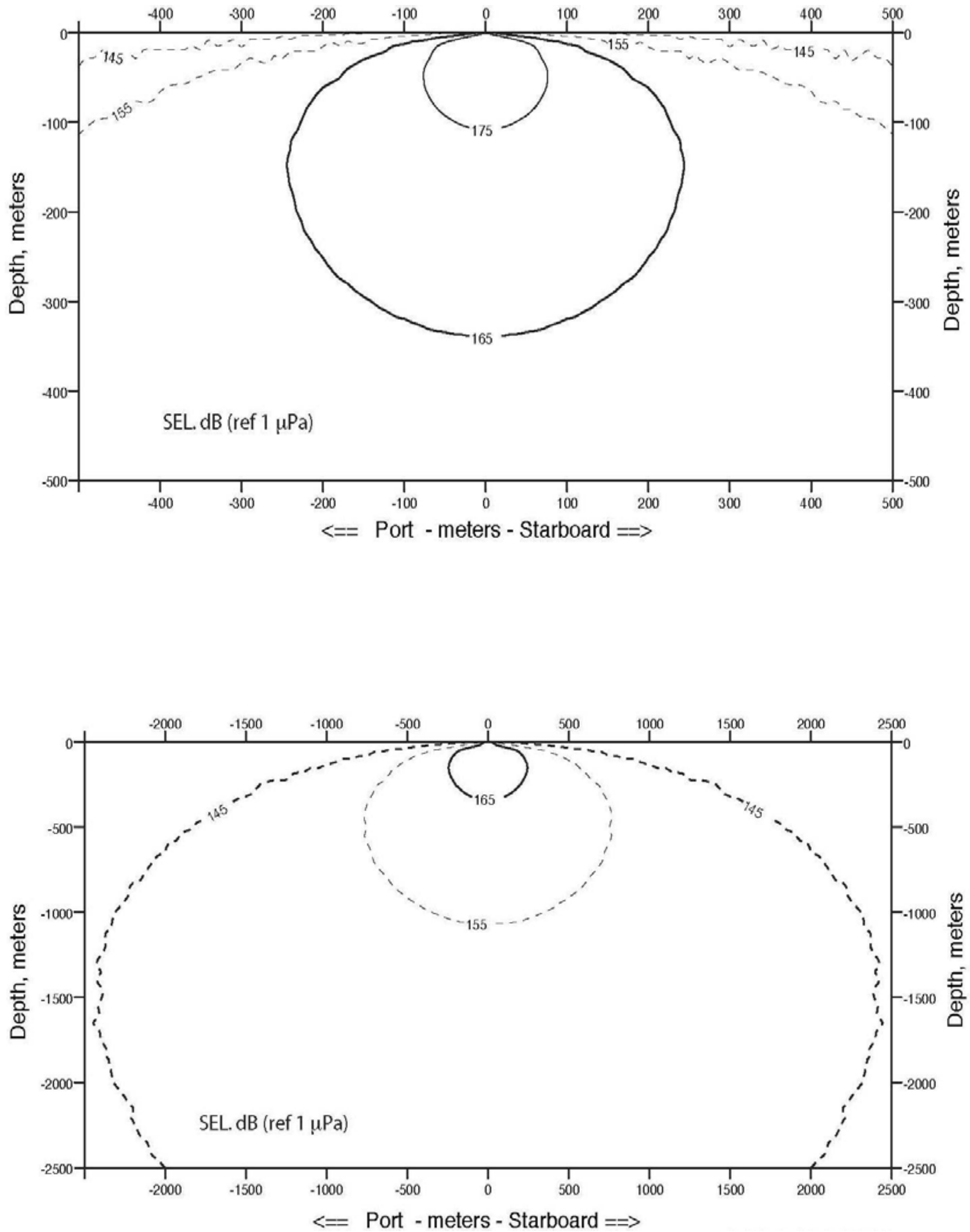


FIGURE 5. Modeled received sound levels from the 4-GI gun array (4 x 105 in^3 GI airguns) that will be used during the UTIG survey in the Arctic Ocean during 2006, assuming an operating depth of 6 m. The model does not allow for bottom interactions, so is most directly applicable to deep-water situations. Model results are provided by L-DEO. The two panels show the same predicted values, with the top panel being an enlargement of the near-source portion of the bottom panel.

The airguns will be powered down (or shut down if necessary) immediately when cetaceans or pinnipeds are detected within or about to enter the appropriate radii. The 180 and 190 dB safety criteria are consistent with guidelines listed for cetaceans and pinnipeds, respectively, by NMFS (2000) and other guidance by NMFS.

UTIG is aware that NMFS may release new noise-exposure guidelines soon (NMFS 2005). See http://mmc.gov/sound/plenary2/pdf/gentryetal.pdf for preliminary recommendations concerning the new criteria. UTIG will be prepared to revise its procedures for estimating numbers of mammals "taken", safety radii, etc., as may be required by the new guidelines, if issued.

Description of Operations

During the seismic survey in the Arctic Ocean, the *Healy* will deploy two different airgun configurations and tow a 200-m long hydrophone streamer. The survey well span from >150 km (81 n.mi) off the coast of Barrow, Alaska, to the Western Canada Basin, Chukchi Borderland and Mendeleev Ridge in the Arctic Ocean. The survey will consist of a total of ~3625 km of surveys, not including transits when the airguns are not operating, plus scientific coring at (at least) seven locations (Fig. 1). The seismic survey will take place in water depths 40–3858 m. Little more than 8% of the survey (~300 km) will occur in water depths <100 m, 23% of the survey (~838 km) will be conducted in water 100–1000 m deep, and most (69%) of the survey (~2486 km) will occur in water deeper than 1000 m.

The *Healy* will rendezvous with the science party off Barrow ~15 July. The *Healy* will then sail north and arrive at the beginning of the seismic survey, which will start >150 km north of Barrow. The entire cruise will last for ~40 days and it is estimated that the total seismic survey time will be ~30 days depending on ice conditions. Deployment and recovery of SISs, or sonobuoys if operating in open water, will occur in a leap-frog fashion during seismic reflection surveys using the vessel-based helicopter. Seismic survey work is scheduled to terminate west of Barrow ~25 August. At least seven coring sites are planned (Fig. 1), but several more may be identified and sampled depending on the ability to deploy SISs given ice and weather conditions. The vessel will then sail south to Nome where the science party will disembark.

Other Acoustic Devices

Along with the airgun operations, additional acoustical systems will be operated during much of or the entire cruise. The ocean floor will be mapped with a multibeam sonar, and a sub-bottom profiler will be used. These two systems are commonly operated simultaneously with an airgun system. An acoustic Doppler current profiler will also be used through the course of the project, as well as a pinger.

Multibeam Echosounder (SeaBeam 2112)

A SeaBeam 2112 multibeam 12 kHz bathymetric sonar system will be used on the *Healy*, with a maximum source output of 237 dB re 1 µPa at one meter. The transmit frequency is a very narrow band, less than 200 Hz, and centered at 12 kHz. Pulse lengths range from less than one millisecond to 12 ms. The transmit interval ranges from 1.5 s to 20 s, depending on the water depth, and is longer in deeper water. The SeaBeam system consists of a set of underhull projectors and hydrophones. The transmitted beam is narrow (~2°) in the fore-aft direction but broad (~132°) in the cross-track direction. The system combines this transmitted beam with the input from an array of receiving hydrophones oriented perpendicular to the array of source transducers, and calculates bathymetric data (sea floor depth and some indications about the character of the seafloor) with an effective 2° by 2° foot print on the seafloor. The

SeaBeam 2112 system on the *Healy* produces a useable swath width of slightly more than 2 times the water depth. This is narrower than normal because of the ice-protection features incorporated into the system on the *Healy*.

Hydrographic Sub-bottom Profiler (Knudsen 320BR)

The Knudsen 320BR will provide information on sedimentary layering, down to between 20 and 70 m, depending on bottom type and slope. It will be operated with the multibeam bathymetric sonar system that will simultaneously map the bottom topography.

The Knudsen 320BR sub-bottom profiler is a dual–frequency system with operating frequencies of 3.5 and 12 kHz:

> Low frequency.-- Maximum output power into the transducer array, as wired on the Healy (125 ohms), at 3.5 kHz is approximately 6000 watts (electrical), which results in a maximum source level of 221 dB re 1 μPa at 1 m downward. Pulse lengths range from 1.5 to 24 ms with a bandwidth of 3 kHz (FM sweep from 3 kHz to 6 kHz). The repetition rate is range dependent, but the maximum is a 1% duty cycle. Typical repetition rate is between 1/2 s (in shallow water) to 8 s in deep water.
>
> High frequency.--The Knudsen 320BR is capable of operating at 12 kHz; but the higher frequency is rarely used because it interfers with the SeaBeam 2112 multibeam sonar, which also operates at 12 kHz. The calculated maximum source level (downward) is 215 dB re 1 μPa at 1 m. The pulse duration is typically 1.5 to 5 ms with the same limitations and typical characteristics as the low frequency channel.

A single 12 kHz transducer and one 3.5 kHz, low frequency (sub-bottom) transducer array, consisting of 16 elements in a 4 × 4 array will be used for the Knudsen 320BR. The 12 kHz transducer (TC-12/34) emits a conical beam with a width of 30° and the 3.5 kHz transducer (TR109) emits a conical beam with a width of 26°.

12-kHz Pinger (Benthos 2216)

A Benthos 12-kHz pinger may be used during coring operations, to monitor the depth of the corer relative to the sea floor. The pinger is a battery-powered acoustic beacon that is attached to the coring mechanism. The pinger produces an omnidirectional 12 kHz signal with a source output of ~192 dB re 1 μPa-m at a one pulse per second rate. The pinger produces a single pulse of 0.5, 2 or 10 ms duration (hardware selectable within the unit) every second.

Acoustic Doppler Current Profiler (150 kHz)

The 150 kHz acoustic Doppler current profiler (ADCP™) has a minimum ping rate of 0.65 ms. There are four beam sectors, and each beamwidth is 3°. The pointing angle for each beam is 30° off from vertical with one each to port, starboard, forward and aft. The four beams do not overlap. The 150 kHz ADCP's maximum depth range is 300 m.

Acoustic Doppler Current Profiler (RD Instruments Ocean Surveyor 75)

The Ocean Surveyor 75 is an ADCP operating at a frequency of 75 kHz, producing a ping every 1.4 s. The system is a four-beam phased array with a beam angle of 30°. Each beam has a width of 4°, and there is no overlap. Maximum output power is 1 kW with a maximum depth range of 700 m.

II. DATES, DURATION, AND REGION OF ACTIVITY

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

The *Healy* will rendezvous with the science party off Barrow ~15 July. The *Healy* will then sail north and arrive at the beginning of the seismic survey, which will start >150 km north of Barrow. The cruise will last for ~40 days, and it is estimated that the total seismic survey time will be ~30 days depending on ice conditions. Seismic survey work is scheduled to terminate west of Barrow about 25 August. The vessel will then sail south to Nome where the science party will disembark.

The seismic survey and coring activities will take place in the Arctic Ocean (Fig. 1). The overall area within which the seismic survey will occur is located approximately between 71º36' and 79º25'N, and between 151º57'E and 177º24'E (Fig. 1). The bulk of the seismic survey will not be conducted in any country's territorial waters. However, the survey will occur within the Exclusive Economic Zone (EEZ) of the U.S. for ~563 km.

III. SPECIES AND NUMBERS OF MARINE MAMMALS IN AREA

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

A total of 8 cetacean species, 4 species of pinnipeds, and 1 marine carnivore are known to or may occur in or near the proposed study area (Table 3). Two of these species, the bowhead and fin whale, are listed as "Endangered" under the ESA, but the fin whale is unlikely to be encountered along the planned trackline.

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 the subject of the IHA Application to NMFS; in the U.S., the walrus and polar bear are managed by the Fish & Wildlife Service.

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

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

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

Sections III and IV are integrated here to minimize repetition.

TABLE 3. The habitat, abundance (in the North Chukchi and Beaufort Sea), and conservation status of marine mammals inhabiting the proposed study area.

Species	Habitat	Abundance	ESA[1]	IUCN[2]	CITES[3]
Odontocetes Beluga whale (*Delphinapterus leucas*)	Offshore, Coastal, Ice edges	50,000[4] 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*)	Coastal, inland waters	Extralimital	Not listed	VU	II
Mysticetes Bowhead whale (*Balaena mysticetus*)	Pack ice & coastal	10,545[7]	Endangered	LR-cd	I
Gray whale (*Eschrichtius robustus*) (eastern Pacific population)	Coastal, lagoons	488[8] 17,500[9]	Not listed	LR-cd	I
Minke whale (*Balaenoptera acutorostrata*)	Shelf, coastal	0	Not listed	LR-cd	I
Fin whale (*Balaenoptera physalus*)	Slope, mostly pelagic	0	Endangered	EN	I
Pinnipeds Walrus (*Odobenus rosmarus*)	Coastal, pack ice, ice	188,316[10]	Not listed	-	II
Bearded seal (*Erignathus barbatus*)	Pack ice	300,000-450,000[11] 4863[12]	Not listed	-	-
Spotted seal (*Phoca largha*)	Pack ice	1000[13]	Not listed	-	-
Ringed seal (*Pusa hispida*)	Landfast & pack ice	Up to 3.6 million [14] 245,048[15] 326,500[16]	Not listed	-	-
Carnivora Polar bear (*Ursus maritimus*)	Coastal, ice	>2500[17] 15,000[18]	Not listed	LR-cd	-

[1] 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).
[4] Total Western Alaska population, including Beaufort Sea animals that occur there in winter (Small and DeMaster 1995).
[5] Beaufort Sea population (IWC 2000).
[6] Population in Baffin Bay and the Canadian arctic archipelago is ~60,000 (DFO 2004); very few enter the Beaufort Sea.
[7] Abundance of bowheads surveyed near Barrow, as of 2001 (George et al. 2004); revised to 10,545 by Zeh and Punt (2005).
[8] Southern Chukchi Sea and northern Bering Sea (Clark and Moore 2002).
[9] North Pacific gray whale population (Rugh 2003 *in* Keller and Gerber 2004).
[10] Pacific walrus population (USFWS 2000a).
[11] Alaska population (USDI/MMS 1996).
[12] Eastern Chukchi Sea population (NMML, unpublished data).
[13] Alaska Beaufort Sea population (USDI, MMS 1996).
[14] Alaska estimate (Frost et al. 1988 *in* Angliss and Lodge 2004).
[15] Bering/Chukchi Sea population (Bengston et al. 2000).
[16] Alaskan Beaufort Sea population estimate (Amstrup 1995).
[17] Amstrup et al (2001).

[18] NWT Wildlife and Fisheries, http://www.nwtwildlife.rwed.gov.nt.ca/Publications/speciesatriskweb/polarbear.htm

The marine mammal species most likely to be encountered during the seismic survey include one or perhaps two cetacean species (beluga and perhaps bowhead whale), three pinniped species (ringed seal, bearded seal, and walrus), and the polar bear. However, most of these will occur in low numbers and encounters with most species are likely to be most common within 100 km of shore where no seismic work is planned to take place. The marine mammal most likely to be encountered throughout the cruise is the ringed seal. Concentrations of walruses might also be encountered in certain areas, depending on the location of the edge of the pack ice relative to their favored shallow-water foraging habitat. The most widely distributed marine mammals are expected to be the beluga, ringed seal, and polar bear.

Three additional cetacean species, the gray whale, minke whale and fin whale, could occur in the project area. It is unlikely that gray whales will be encountered near the proposed trackline; if encountered at all, gray whales would be found closer to the Alaska coastline where no seismic work is planned. Minke and fin whales are extralimital in the Chukchi Sea and will not likely be encountered as the proposed trackline borders their known range. Two additional pinniped species, the harbor and spotted seal, are also unlikely to be seen.

(1) Odontocetes

(a) Beluga (*Delphinapterus leucas*)

The 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).

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 the Beaufort Sea stock and eastern Chukchi Sea stocks may be encountered. Some eastern Chukchi Sea animals enter the Beaufort Sea in late summer (Suydam et al. 2001).

The Beaufort population was estimated to contain 39,258 individuals as of 1992 (Angliss and Lodge 2002). This estimate is 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 population and may be an under-estimate 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 (DeMaster 1995).

Beluga whales from the eastern Chukchi Sea stock are an important subsistence resource for residents of the village of Point Lay, adjacent to Kasegaluk Lagoon, and other villages in northwest Alaska. Each year, hunters from Point Lay drive belugas into a lagoon to a traditional hunting location. The belugas have been predictably sighted near the lagoon from late June through mid to late July (Suydam et al. 2001). Lowry (2001) tagged 5 male belugas with satellite tracking devices in Kasegaluk Lagoon in June/July 1998. Using the telemetry location of one beluga that remained relatively nearshore, a group of 11,035 animals were located and counted during an aerial survey near Icy Cape and in the ice just offshore on 6 July (Lowry et al. 1999 *in* Lowry 2001). Four of the tagged belugas moved far north into deep offshore Arctic Ocean waters with heavy ice cover (more than 90%), north of Point Barrow. Three of the five tagged belugas traveled north of 80°N, ~1100 km north of the Alaska coast. One of those belugas remained at 80°N for a week; it was speculated that this whale was taking advantage of a resource there, perhaps Arctic cod. The abundance estimate considered the "most reliable" for the eastern Chukchi Sea beluga whale stock is 3710, a result from 1989–1991 aerial surveys (Angliss and Lodge 2004). The population size is considered stable. It is possible that whales of the eastern Chukchi Sea beluga stock will be encountered.

Beluga whales of the Beaufort stock winter in the Bering Sea, summer in the eastern Beaufort Sea, and migrate around western and northern Alaska (Angliss and Lodge 2002). 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. 1995).

Much of the Beaufort Sea seasonal population enters in 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 and Amundsen Gulf (Davis and Evans 1982; Harwood et al. 1996; Richard et al. 2001). Belugas are rarely seen in the central Alaskan Beaufort Sea during the summer. During late summer and autumn, most belugas migrate far offshore near the pack ice front (Frost et al. 1988; Hazard 1988; Clarke et al. 1993; Miller et al. 1999). Moore (2000) and Moore et al. (2000b) suggest that beluga whales select deeper slope water independent of ice cover. However, during the westward migration in late summer and autumn, small numbers of belugas are sometimes seen near the north coast of Alaska (e.g., Johnson 1979). Nonetheless, the main fall migration corridor of beluga whales is ~100+ km north of the coast. Satellite-linked telemetry data show that some belugas migrate west considerably farther offshore, as far north as 76º to 78ºN latitude (Richard et al. 1997, 2001).

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). 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).

Although beluga whales are largely absent from the central Alaska coast during the summer, a few beluga whales could be encountered from the Alaskan coast to the northernmost point of the study area ~80ºN.

Very few beluga whale survey data, specific to the area of the proposed seismic cruise, are available. Density estimates of beluga whales that are most applicable to this project are for the eastern Beaufort Sea area. Because this survey will take place in the Arctic Ocean (primarily) and northern Beaufort and Chukchi seas (minimally), a fraction of the Beaufort Sea density estimate has been applied as possible beluga whale densities that will be encountered during the survey.

(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). The species is rarely seen in Alaskan waters or the Beaufort Sea generally. Thus, it is possible, but very unlikely that individuals will be encountered in this far west portion of their range.

Narwhal movements follow the sea ice. In the spring, as the ice breaks up, they follow the receding ice edge and enter deep sounds and fjords, where they stay during the summer and early fall

(Reeves et al. 2002). When the ice reforms, narwhals move to offshore areas in the pack ice (Reeves et al. 2002), living in leads in the heavy pack ice throughout the winter. Most pods consist of 2–10 individuals but they may aggregate to form larger herds of hundreds or even thousands of individuals (Jefferson et al. 1993). According to Hay (1985), segregation by age and sex within this population is evident, with summering groups consisting of mature females with calves, immature and maturing males, and large mature males.

No narwhals are expected to be encountered during the proposed activity. If narwhals are observed during the survey, they would most likely be seen along the eastern portions of the proposed trackline where they would be considered extralimital.

(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 tropical and polar waters. High densities of this species occur in high latitudes, especially in areas where prey is abundant. The greatest abundance is thought to occur within 800 km of major continents (Mitchell 1975). Killer whales appear to prefer coastal areas, but are also known to occur in deep water (Dahlheim and Heyning 1999).

Killer whales are known to inhabit almost all coastal waters of Alaska, extending from the Bering and Chukchi seas into the Beaufort Sea. The size of the Beaufort Sea population is not known but apparently very small; ~100 animals have been identified in the Bering Sea where the species is more common (ADFG 1994).

Although resident in some parts of their range, killer whales can also be transient. Killer whale movements generally appear to follow the distribution of prey.

The living generations of natives have never seen killer whales near Barrow, although their ancestors have seen killer whales. Killer whales are unlikely to be encountered during the proposed seismic survey.

(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). Harbor porpoises typically occur in small groups of only a few individuals and tend to avoid vessels (Richardson et al. 1995). They feed on small schooling fish (Read 1999).

The subspecies *P. p. vomerina* ranges from the Chukchi Sea, Pribilof Islands, Unimak Island, and the south-eastern shore of Bristol Bay south to San Luis Obispo Bay, 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.

Given the harbor porpoise's vagrant status in the Beaufort Sea, and the fact that it is mainly a shallow-water species, encounters with this species are highly unlikely, especially in the far-offshore waters where the seismic survey is to occur.

(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). They are 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.

Bering–Chukchi–Beaufort stock: In Alaskan waters, bowhead whales winter in the central and western Bering Sea and summer in the Canadian Beaufort Sea (Moore and Reeves 1993). Spring migration through the western Beaufort Sea occurs through offshore ice leads, generally from mid-April through mid-June (Braham et al. 1984; Moore and Reeves 1993).

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 in the Canadian Beaufort Sea, bowheads migrate westward from late August through mid or late October. 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). 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.).

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). Numbers of bowhead whales, their location, distribution, and direction of movement have been documented.

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). 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. Research suggests that during the fall migration, bowhead whales alter course in response to seismic sounds >130 dB dB re 1 μPa rms (Richardson et al. 1986; Richardson et al. 1999). However, summering bowheads do not appear to be as sensitive to seismic sounds (Miller et al. 2005) and may not alter behaviors until received sounds are in the 160 dB dB re 1 μPa rms range. 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.

Bowhead whales typically reach the Barrow area during their westward migration from the feeding grounds in the Canadian Beaufort Sea in mid-September to late October. However, over the years, local residents report having seen a small number of bowhead whales feeding off Barrow or in the pack ice off Barrow during the summer. Autumn bowhead whaling near Barrow normally begins in mid-September, but may begin as early as August if whales are observed and ice conditions are favorable (USDI/BLM 2005). Whaling can continue into October, depending on the quota and conditions.

The pre-exploitation population of bowhead whales in the Bering, Chukchi, and Beaufort seas is estimated to have been 10,400-23,000 whales, and that was reduced by commercial whaling to perhaps 3000 (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; Angliss and Lodge 2002) despite annual subsistence harvests of 14–74 bowheads from 1973 to 1997 (Suydam et al. 1995; Section IV). Allowing for an additional census in 2001, the latest estimates are an 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). Assuming a continuing annual population growth of 3.4%, the 2005 bowhead population may number around 12,000 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 Bering–Chukchi–Beaufort bowhead population is currently listed as "Endangered" under the ESA and is classified as a strategic stock by the NMFS (Angliss and Lodge 2002).

Given the migratory patterns of bowhead whales in the western Beaufort Sea and results of other recent cruises (Harwood et al. 2005; Haley and Ireland 2006), few bowhead whales are expected to be encountered during the proposed cruise. The early scheduling of this cruise was timed to avoid the main autumn migration period of bowheads. This cruise will be completed at about the time that bowheads are expected to begin arriving in the Alaskan Beaufort.

Offshore bowhead whale distribution is not well documented. The best available bowhead whale densities that apply to this project are derived from summer surveys in the Beaufort Sea, far to the southeast of the proposed survey. The applied bowhead whale density estimates are fractions of those calculated from the Beaufort Sea surveys as densities in the project area are expected to be much lower than observed in the Beaufort Sea (Tables 4 and 5).

(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 26,635 in 1998 (Rugh et al. 1999; Angliss and Lodge 2002; NMFS 2002). However, abundance estimates since 1998 indicate a consistent decline, and Rugh (2003 *in* Keller and Gerber 2004) estimated the population to be 17,500 in 2002. The eastern Pacific stock is not considered by NMFS to be a strategic stock.

Eastern Pacific gray whales breed and calve in the protected waters along the west coast of Baja California and the east coast of the Gulf of California from January to April (Swartz and Jones 1981; Jones and Swartz 1984). At the end of the breeding and calving season, most of these gray whales migrate about 8000 km, generally along the west coast, to the main summer feeding grounds in the northern Bering and Chukchi seas (Tomilin 1957; Rice and Wolman 1971; Braham 1984; Nerini 1984).

Most summering gray whales congregate in the northern Bering Sea, particularly off St. Lawrence Island and 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. The northeastern-most of the recurring feeding areas is in the northeastern Chukchi Sea southwest of Barrow (Clarke et al. 1989). Only a small number of gray whales enter the Beaufort Sea east of Point Barrow. In recent years, ice conditions have become lighter near Barrow, and gray whales may have become more common. 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 (Harwood et al. 2005) or on a recent *Healy* cruise in 2005 (Haley and Ireland 2006).

Given the rare occurrence of gray whales in the Beaufort Sea in summer, and the fact that most of the seismic survey is northwest of Barrow, no more than a few are expected to be in the region during the proposed activity. Those gray whales that are in the Beaufort Sea would be expected to remain close to shore and thus distant from the proposed seismic activity. Gray whales would most likely be encountered, if at all, at the beginning and end of the cruise in ice-free areas closer to shore. Since the majority of the planned activities are further offshore than where gray whales are expected to be found, few interactions are expected.

Survey data for gray whales in the Alaskan Arctic extend into the Chukchi Sea near the southwest portion of the proposed seismic survey and along the coast near Pt. Barrow. Proportions of the gray whale densities estimated from the available survey data have been used to estimate densities of gray whales that may be encountered during the proposed project.

(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. In the North Pacific, minke whales range into the Bering and Chukchi seas but do not range into the Alaskan Beaufort Sea. It is extremely unlikely that minke whales will be observed in the northern Chukchi Sea portion of the proposed survey.

(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 regions. Fin whales feed in northern latitudes during the summer where their prey includes plankton as well as shoaling pelagic fish, such as capelin *Mallotus villosus* (Jonsgård 1966). The North Pacific population summers from the Chukchi Sea to California (Gambell 1985), but does not range into the Alaskan Beaufort Sea or waters of the northern Chukchi Sea. The fin whale is listed as "Endangered" under the ESA and by IUCN, and it is a CITES Appendix I species (Table 3). It is expected that no fin whales will be encountered during the proposed project.

(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 Pacific subspecies is potentially within the planned seismic survey study area.

Estimates of the pre-exploitation population of the Pacific walrus range from 200,000 to 400,000 animals (USFWS 2000a). Over the past 150 years, the population has been depleted by over-harvesting and then periodically allowed to recover (Fay et al. 1989). The most current minimum population estimate is 188,316 walruses (USFWS 2000a). This estimate is conservative, because a portion of the Chukchi Sea was not surveyed due to lack of ice. The U.S. Fish and Wildlife Service (USFWS), in partnership with other U.S. agencies and Russian scientists, is currently launching a concerted and substantial effort to investigate new techniques for producing a more precise (CV ≤ 0.4) abundance estimate of Pacific walrus. The results of these survey efforts should be available in 2007 (USFWS 2006).

The Pacific walrus ranges from the Bering Sea to the Chukchi Sea, occasionally moving into the East Siberian and Beaufort seas. Walruses are migratory, moving south with the advancing ice in autumn and north as the ice recedes in spring (Fay 1981). In the summer, most of the population of Pacific walrus moves to the Chukchi Sea, but several thousands aggregate in the Gulf of Anadyr and in Bristol Bay (Angliss and Lodge 2004). 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 walrus, and only a few are seen farther east in the Beaufort Sea (e.g., Harwood et al. 2005). Walruses observed in the Beaufort Sea have typically been lone individuals. The reported subsistence harvest of walruses for Barrow for the 5-year period of 1994-1998 was 99 walruses (USDI 2000a). Most of these were harvested west of Point Barrow. In addition, between 1988 and 1998, Kaktovik harvested one walrus (USDI 2000b).

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, floating them on to new foraging habitat and providing a place to rest and nurse their young.

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 ice pack, walruses are found further offshore with principal concentrations to the northwest of Barrow. By October, a reverse migration occurs out of the Chukchi Sea, with animals swimming ahead of the developing pack ice, as it is too weak to support them (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 10–50 m (Vibe 1950; Fay 1982). 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 the clams and other mollusks walruses prefer are found (Fay 1982; Fay and Burns 1988; Reeves et al. 2002).

The proposed seismic work will take place in depths from ~41–3836 m of water. A small proportion of the seismic work, ~292 km (~8%), is expected to occur at depths where walruses prefer to forage (<80 m). Coring is planned north of 77°N which is well beyond the known summer range of the walrus. It is unlikely that the *Healy* will encounter Pacific walruses once it commences the seismic survey >150 km off the coast to the north. The majority (~92%) of seismic work will occur in water deeper than that preferred by walruses (<80 m) and beyond the far northeastern limits of their summer range. During a survey through the northern Chukchi Sea in early August of 2005, only three walruses were sighted and none were further north than 72.8°N (Haley and Ireland 2006). There is an increased chance of encountering walrus groups on the return segment of the cruise (south of 75°N), as ~46% of this segment traverses water <80 m deep bordering the northeastern extent of their summer range.

Besides depending on the depth of water in which the *Healy* will work, the probability of encountering Pacific walruses along the proposed trackline will depend on the location of the southern edge of the pack ice and the timing of spring break-up. It is highly unlikely that the *Healy* will encounter Pacific walruses as she commences the seismic survey >150 km north of the coast. This area is well beyond the historical range where walruses are found in mid- to late July and presumably too deep for benthic foraging.

On the return trip, there is an increased likelihood that the ship may encounter walruses as the survey approaches areas of known walrus concentrations. This portion of the northern Chukchi Sea has shallow water depths over the continental shelf and less concentrated pack-ice making foraging more efficient for walruses.

(b) Bearded Seal (*Erignathus barbatus*)

Bearded seals are associated with sea ice and have a circumpolar distribution (Burns 1981). During the open-water period, bearded seals occur mainly in relatively shallow areas, because they are predominantly benthic feeders (Burns 1981). They prefer areas of water no deeper than 200 m (e.g., Harwood et al. 2005).

In Alaskan waters, bearded seals occur over the continental shelves of the Bering, Chukchi, and Beaufort seas (Burns 1981). The Alaska stock of bearded seals may consist of about 300,000–450,000 individuals (MMS 1996). No reliable estimate of bearded seal abundance is available for the Beaufort Sea (Angliss and Lodge 2002). The Alaska stock of bearded seals is not classified by NMFS as a strategic stock.

The bearded seal is the largest of the northern phocids. Bearded seals have occasionally been reported to maintain breathing holes in sea ice and broken areas within the pack ice, particularly if the water depth is <200 m. Bearded seals apparently also feed on ice-associated organisms when they are present, and this allows a few bearded seals to live in areas considerably 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 of the bearded seals that overwintered in the Bering Sea migrate northward through the Bering Strait. During the summer they are found near the widely fragmented margin of multi-year ice covering the continental shelf of the Chukchi Sea and in nearshore areas of the central and western Beaufort Sea. In the Beaufort Sea, bearded seals rarely use coastal haulouts.

In some areas, bearded seals are associated with the ice year-round; however, they usually move shoreward into open water areas when the pack ice retreats to areas with water depths greater than 200 m. During the summer, when the Bering Sea is ice-free, the most favorable bearded seal habitat is found in the central or northern Chukchi Sea along the margin of the pack ice. Bearded seal densities in the pack ice of the northern Chukchi see appear to be low as only three bearded seals were observed during a survey that passed through the proposed seismic survey area in early August of 2005 (Haley and Ireland

2005). Suitable habitat is more limited in the Beaufort Sea where the continental shelf is narrower and the pack ice edge frequently occurs seaward of the shelf and over water too deep for benthic feeding. The preferred habitat in the western and central Beaufort Sea during the open water period is the continental shelf seaward of the scour zone.

The proposed seismic survey is to be conducted beyond 150 km of shore, and the majority of that (~91% or >3285 km) will occur in water >200 m. The *Healy* is expected to encounter few bearded seals during the proposed survey, most likely in shallower water.

(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 total number of spotted seals in Alaskan waters is not known (Angliss and Lodge 2002), 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 a strategic stock by NMFS (Hill and DeMaster 1998).

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. The seals are commonly seen in bays, lagoons and estuaries, but also range far offshore as far north as 69–72ºN. In summer, they are rarely seen on the pack ice, except when the ice is very near to shore. As the ice cover thickens with the onset of winter, spotted seals leave the northern portions of their range and move into the Bering Sea (Lowry et al. 1998).

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 recent times <20 seals have been seen at any one site (Johnson et al. 1999). In total, there are probably no more than a few tens of spotted seals along the coast of the central Alaska Beaufort Sea during summer and early fall. 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). No spotted seals were identified during MMS's fall 2000 and 2001 aerial surveys in the Beaufort Sea (Treacy 2002a,b).

The *Healy* is expected to encounter only a few spotted seals during the first and last portions of its trackline (south of 72ºN), where only ~123 km of seismic operations are planned.

(d) Ringed Seal (*Pusa hispida*)

Ringed seals have a circumpolar distribution and occur in all seas of the Arctic Ocean (King 1983). They are closely associated with ice, and in the summer they often occur along the receding ice edges or farther north in the pack ice. In the North Pacific, they occur in the southern Bering Sea and range south to the seas of Okhotsk and Japan. They are found throughout the Beaufort, Chukchi, and Bering seas (Angliss and Lodge 2004).

Ringed seals are year-round residents in the northern Chukchi and Beaufort Seas and are 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 Lodge 2002). 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) estimate the Alaskan Beaufort Sea population at 326,500 animals. The Alaska stock of ringed seals is not classified as a strategic stock by the NMFS.

Marine mammal observers aboard the *Healy* sighted as many as 50 ringed seals along 2401 km of trackline between 70°N and 81°N during two weeks of travel in August 2005. During oceanographic research in the northern Chukchi Sea in late August of 2002, Harwood et al. (2005) did not observe any ringed seals along a route bordering the proposed study area.

During winter, ringed seals occupy landfast ice and offshore pack ice of the Bering, Chukchi and Beaufort seas. 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). Ringed seals maintain breathing holes in the ice and occupy lairs in accumulated snow (Smith and Stirling 1975). They 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 seal densities are not available for the area of the proposed survey. The most applicable density data described above are from surveys in the pack ice in the Beaufort Sea and have been applied as densities for 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 six major populations and many sub-populations based on mark-and-recapture studies (Lentfer 1983), radio telemetry studies (Amstrup and Gardner 1994), and morphometrics (Manning 1971; Wilson 1976). Polar bears are common in the Chukchi and Beaufort seas north of Alaska throughout the year, including the late summer 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 ~20,000–30,000 bears (Derocher et al. 1998). Amstrup (1995) estimated the minimum population of polar bears for the Beaufort Sea to be ~1500–1800 individuals, with an average density of about one bear per 38.6 to 77.2 square miles (100–200 km^2). There are no reliable data on the population status of polar bears in the Bering/Chukchi Sea; an estimate was derived by subtracting the total estimated Alaska polar bear population from the Beaufort Sea population, thus yielding an estimate of 1200–3200 animals (Amstrup 1995).

The Alaskan polar bear population is considered to be stable or increasing slightly (USFWS 2000b,c). Polar bear populations located in the Southern Beaufort Sea have been estimated to have an annual growth rate of 2.2–2.4% with an annual harvest of only 1.9% (Amstrup 1995). Currently, neither stock is listed as "depleted" under the Marine Mammal Protection Act, or as "Threatened" or "Endangered" under the ESA (USFWS 2000b,c). Polar bear populations are protected under the MMPA, 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."

The Southern Beaufort Sea population ranges from the Baillie Islands, Canada, in the east to Point Hope, Alaska, in the west. The Bering/Chukchi Sea population ranges from Point Barrow, Alaska, in the east to the Eastern Siberian Sea in the west. These two populations overlap between Point Hope and Point Barrow, Alaska, centered near Point Lay (Amstrup 1995). Both of these populations have been extensively studied by tracking the movement of tagged females (Garner et al. 1990). Radio-tracking studies indicate significant movement within populations and occasional movement between populations (Garner et al. 1990; Amstrup 1995). For example, a female polar bear within sight of the Prudhoe Bay oilfields was captured, fitted with a satellite-tracking collar, and her movements monitored for 576 days. She traveled north and then south to Greenland, traversing ~7162 km in 576 days (Durner and Amstrup 1995). During fall 2000 (Treacy 2002a) aerial surveys, a total of 23 bears (in 9 sightings) were sighted in the Beaufort Sea, along with 28 sets of tracks. In fall 2001 (Treacy 2002b), 6 polar bears were observed in 4 sightings; 43 sets of tracks were also seen. MMS bowhead whale aerial surveys since 1979 have documented an increase, starting in 1992, in the proportion of polar bears associated with land vs. sea-ice in the fall season (Monnett et al. 2005). In 2004, a large number of bears were observed swimming >2 km offshore, and a number of polar bear carcasses were subsequently observed offshore. Monnett et al (2005) suggest that as the pack ice edge moves northward, drowning deaths of polar bears may increase. The number of polar bears encountered in open water may therefore be slightly higher than previously expected.

Polar bears usually forage in areas where there are high concentrations of ringed 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), at about 88°N their population thins dramatically. However, polar bears have been observed across the Arctic, including close to the North Pole (van Meurs and Splettstoesser 2003). Three polar bears were observed from the *Healy* in the northern Chukchi Sea during a survey through this area in August of 2005 (Haley and Ireland 2006). These three sightings occurred along 2401 km of observed trackline over 14 days between 70°N and 81°N.

The *Healy* is likely to encounter polar bears when it enters the pack ice. Small numbers of bears could be encountered anywhere along the entire trackline.

V. Type of Incidental Take Authorization Requested

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

UTIG requests an IHA pursuant to Section 101(a)(5)(D) of the MMPA for incidental take by harassment during its planned geophysical survey in the Arctic Ocean during July–August 2006.

The operations outlined in § I and II have the potential to take marine mammals by harassment. Sounds will mainly be generated by the airguns used during the survey, by a bathymetric sonar, a sub-bottom profiler sonar, pinger, and by general vessel operations. “Takes” by harassment will potentially result when marine mammals near the activities are exposed to the pulsed sounds generated by the airguns or sonars. The effects will depend on the species of cetacean or pinniped, the behavior of the animal at the time of reception of the stimulus, as well as the distance and received level of the sound (see § VII). Disturbance reactions are likely among some of the marine mammals in the general vicinity of the tracklines of the source vessel. No take by serious injury is anticipated, given the nature of the planned operations and the mitigation measures that are planned (see § XI, “Mitigation Measures”). No lethal takes are expected.

VI. Numbers of Marine Mammals That May be Taken

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

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

VII. Anticipated Impact on Species or Stocks

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

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

- First we summarize the potential impacts on marine mammals of airgun operations, as called for in Section VII. A more comprehensive review of the relevant background information appears in Appendix A.
- Then we discuss the potential impacts of operations by the bathymetric sonar, sub-bottom profiler, and pinger.
- Finally, we estimate the numbers of marine mammals that might be affected by the proposed activity in the Arctic Ocean in July–August 2006. This section includes a description of the rationale for the estimates of the potential numbers of harassment "takes" during the planned survey, as called for in Section VI.

(a) 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. 1995). Because the airgun sources planned for use during the present project involve only 4 or 8 airguns, the effects are anticipated to be less than would be the case with a large array of airguns. It is very unlikely that there would be any cases of temporary or especially permanent hearing impairment, or non-auditory physical effects. Also, behavioral disturbance is expected to be limited to relatively short distances.

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 A (c). 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 A (e). 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.

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, given the intermittent nature of seismic pulses. 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 A (d).

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 A (e), 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 A (e) 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 A (e)). More recent research on bowhead whales (Miller et al. 2005), however, suggests that during the summer feeding season (during which the proposed project will take place) bowheads are not nearly as sensitive to seismic sources and can be expected to react to the more typical 160–170 dB re 1 μPa rms range.

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.

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. In any event, the brief exposures to sound pulses from the proposed airgun source are highly unlikely to result in prolonged effects.

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 A 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).

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).

Similarly, 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. With the presently-planned source, such levels would be found within ~400 m of the 4 GI guns operating in shallow water.

Odontocete reactions to large arrays of airguns are variable and, at least for small odontocetes, seem to be confined to a smaller radius than has been observed for mysticetes (Apppendix A). A ≥170 dB disturbance criterion (rather than ≥160 dB) is considered appropriate for small odontocetes (and pinnipeds) which tend to be less responsive than other cetaceans. Behavioral reactions of odontocetes to the medium-sized source to be used here are expected to be localized and brief.

Pinnipeds.— Pinnipeds are not likely to show a strong avoidance reaction to the medium-sized airgun sources that will be used. Visual monitoring from seismic vessels has shown only slight (if any) avoidance of airguns by pinnipeds, and only slight (if any) changes in behavior—see Appendix A (e). Those studies show that pinnipeds frequently do not avoid the area within a few hundred meters of operating airgun arrays (e.g., Miller et al. 2005; Harris et al. 2001). 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 present study 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. As for small odontocetes, a ≥170 dB disturbance criterion is considered appropriate for pinnipeds which tend to be less responsive than other marine mammals.

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. 1995).

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). 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 B (f) 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 multi-beam bathymetric sonar), and to avoid exposing them to sound pulses that might, at least in theory, cause hearing impairment [see § 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, 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 present 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 moderate size of the source, and 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).

A marine mammal within a radius of ≤100 m (≤328 ft) 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. The sound level radius would be similar (≤100 m) around the proposed 8-airgun array while surveying in intermediate depths (100–1000 m). This would occur for <23% (~838 km) of the survey when the survey will be conducted in intermediate depths. Also, the PIs propose using the 4 GI guns for some of the intermediate-depth survey, which would greatly reduce the ≥205 dB sound radius. (As noted above, most cetacean species tend to avoid operating airguns, although not all individuals do so.)

However, several of the considerations that are relevant in assessing the impact of typical seismic surveys with arrays of airguns are not directly applicable here:

- "Ramping up" (soft start) is standard operational protocol during startup of large 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 either airgun array is operated.
- 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. In this project, most of the seismic survey will be in deep and water where the radius of influence and duration of exposure to strong pulses is smaller.
- With a large array of airguns, TTS would be most likely in any odontocetes that bow-ride or otherwise linger near the airguns. In the present project, the anticipated 180-dB distances in deep and intermediate-depth water are 716 m and 1074 m, respectively, for the 8-airgun gun system (Table 2) and 246 m and 369 m, respectively for the 4-GI gun system. The waterline at the bow of the *Healy* will be ~123 m ahead of the airgun. 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). The predicted 180 and 190 dB distances for the airguns operated by UTIG vary with water depth. They are estimated to be 716 m and 230 m, respectively, in deep water for the 8-airgun system, and 246 m and 75 m, respectively, in deep water for the 4-GI gun system. In intermediate depths, these distances are predicted to increase to 1074 m and 345 m, respectively for the 8-airgun system, and 369 m and 113 m, respectively for the 4-GI gun system. The predicted 180 and 190 dB distances for the 4-GI gun system in shallow water are 1822 m and 938 m, respectively (Table 2). The 8-airgun array will not be operated in shallow water. Shallow water (<100 m) will occur along only 300 km (~8 %) of the planned trackline. Furthermore, those sound levels 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 and 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 A (f).

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 medium-sized 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, as they would probably need to be within 100–200 m of the airguns for that to occur. 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 airgun 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 is moderately sized, the ship is moving at 3–4 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 shut downs of the airguns, which will reduce any such effects that might otherwise occur.

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 A (g) 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, 8490 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 this project area and the planned monitoring and mitigation measures are expected to minimize any possibility for mortality of other species.

(b) Possible Effects of Bathymetric Sonar Signals

A SeaBeam 2112 multibeam 12 kHz bathymetric sonar system will be operated from the source vessel essentially continuously during the planned study. Details about the SeaBeam 2112 were provided in Section II. Sounds from the multibeam are very short pulses, depending on water depth. Most of the energy in the sound pulses emitted by the multibeam is at moderately high frequencies, centered at 12 kHz. The beam is narrow (~2°) in fore-aft extent and wide (~130º) in the cross-track extent. 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 SeaBeam 2112 at close range are unlikely to be subjected to repeated pulses because of the narrow fore–aft width of the beam, and will receive only limited amounts of pulse energy because of the short pulses. Similarly, Kremser et al. (2005) noted that the probability of a cetacean swimming through the area of exposure when a multibeam sonar emits a pulse is small. 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 SeaBeam 2112 sonar, (2) have a longer pulse duration, and (3) are directed close to horizontally vs. downward for the SeaBeam 2112. The area of possible influence of the bathymetric sonar is much smaller—a narrow band oriented in the cross-track direction below the source vessel. Marine mammals that encounter the bathymetric sonar at close range are unlikely to be subjected to repeated pulses because of the narrow fore-aft width of the beam, and will receive only small amounts of pulse energy because of the short pulses. In assessing the possible impacts of a similar multibeam system (the 15.5 kHz Atlas Hydrosweep multibeam bathymetric sonar), Boebel et al. (2004) noted that the critical sound pressure level at which TTS may occur is 203.2 dB re 1 μPa (rms). The critical region included an area of 43 m in depth, 46 m wide athwartship, and 1 m fore-and-aft (Boebel et al. 2004). In the more distant parts of that (small) critical region, only slight TTS would be incurred.

Masking

Marine mammal communications will not be masked appreciably by the bathymetric sonar signals given the low duty cycle of the sonar and the brief period when an individual mammal is likely to be within the sonar beam. Furthermore, the 12 kHz multibeam 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·m, 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 bathymetric sonars to be used during the proposed study, and a given mammal would have received many pulses from the naval sonars. During UTIG'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 white whale exhibited changes in behavior when exposed to 1 s pulsed sounds at frequencies similar to those that will be emitted by the bathymetric sonar to be used by UTIG, and to shorter broadband pulsed signals. Behavioral changes typically involved what appeared to be deliberate attempts to avoid the sound exposure (Schlundt et al. 2000; Finneran et al. 2002; Finneran and Schlundt 2004). The relevance of those data to free-ranging odontocetes is uncertain, and in any case, the test sounds were quite different in either duration or bandwidth as compared with those from a bathymetric sonar.

We are not aware of any data on the reactions of pinnipeds to sonar sounds at frequencies similar to those of the multibeam sonar (12 kHz). Based on observed pinniped responses to other types of pulsed sounds, and the likely brevity of exposure to the bathymetric sonar sounds, pinniped reactions to the sonar sounds 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 *Healy* or elsewhere at sufficient depth to be in the main beam of the bathymetric sonar, so would not be affected by the sonar sounds.

As noted earlier, NMFS (2001) has concluded that momentary behavioral reactions "do not rise to the level of taking". Thus, brief exposure of cetaceans or pinnipeds to small numbers of signals from a multibeam bathymetric sonar system 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 multibeam sonar proposed for use by UTIG is quite different from sonars used for navy operations. Pulse duration of the bathymetric sonar 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 multibeam sonar for much less time given the generally downward orientation of the beam and its narrow fore-aft beamwidth. (Navy sonars often use near-horizontally-directed sound.) Those factors would all reduce the sound energy received from the bathymetric sonar relative to that from the sonars used by the Navy. Polar bears would not occur in the main beam of the sonar.

(c) Possible Effects of Sub-bottom Profiler Signals

A Knudsen 320BR sub-bottom profiler will be operated from the source vessel at nearly all times during the planned study. Details about the equipment were provided in § II. The Knudsen 320BR produces sound pulses with lengths of up to 24 ms every 0.5 to ~8 s, depending on water depth. The energy in the sound pulses emitted by this sub-bottom profiler is at mid- to moderately high frequency, depending on whether the 3.5 or 12 kHz transducer is operating. The conical beamwidth is either 26°, for the 3.5 kHz transducer, or 30°, for the 12 kHz transducer, and is directed downward.

Source levels for the Knudsen 320 operating at 3.5 and 12 kHz have been measured as a maximum of 221 and 215 dB re 1 μPa m, respectively. Received levels would diminish rapidly with increasing depth. Assuming circular spreading, received level directly below the transducer(s) would diminish to 180 dB re 1 μPa at distances of about 112 m when operating at 3.5 kHz, and 56 m when operating at 12 kHz. The 180 dB distances in the horizontal direction (outside the downward-directed beam) would be substantially less. Kremser et al. (2005) noted that the probability of a cetacean swimming through the area of exposure when a bottom profiler emits a pulse is small, and if the animal was in the area, it would have to pass the transducer at close range and in order to be subjected to sound levels that could cause TTS.

Masking

Marine mammal communications will not be masked appreciably by the sub-bottom profiler signals given its relatively low duty cycle, directionality, and the brief period when an individual mammal is likely to be within its beam. In the case of most odontocetes, the 3.5 kHz sonar signals do not overlap with the predominant frequencies in their calls, which would avoid significant masking. The beluga whale is the only odontocete anticipated in the area of the proposed survey. Though belugas can hear sounds ranging from 1.2 to 120 kHz, their peak sensitivity is ~10-15 kHz, overlapping with the 12 kHz signals but not the 3.5 kHz signals (Fay 1988). Again, it is seldom that the 12 kHz transducer for the Knudsen 320BR will be used because its frequency interferes with the multibeam sonar (§ I above). Neither frequency sonar signals overlap with the predominant low frequencies in baleen whale calls, further reducing potential for masking.

Behavioral Responses

Marine mammal behavioral reactions to other pulsed sound sources are discussed above, and responses to the sub-bottom profiler are likely to be similar to those for other pulsed sources if received at the same levels. However, the pulsed signals from the Knudsen 320BR while the 3.5 kHz transducer is operating are weaker than those from the bathymetric sonar and those from the proposed 4- or 8-airgun arrays. Therefore, behavioral responses are not expected unless marine mammals are close to the source. When the 12 kHz transducer is in operation (which will be seldom because it interferes with the SeaBeam), the behavioral responses to the Knudsen 320BR are expected to be similar to those reactions to the SeaBeam bathymetric sonar system (as discussed above). NMFS (2001) has concluded that momentary behavioral reactions "do not rise to the level of taking". Thus, brief exposure of cetaceans to small numbers of signals from the sub-bottom profiler would not result in a "take" by harassment.

Hearing Impairment and Other Physical Effects

Source frequencies of the Knudsen 320BR are much lower than those of the bathymetric sonar when the 3.5 kHz transducer is engaged. When the 12.5 kHz transducer is operating (which will be seldom because it interferes with the SeaBeam), the source frequency is similar to that of the bathymetric sonar (as discussed above). As with the SeaBeam, the pulses are brief and concentrated in a downward beam. A marine mammal would be in the beam of the sub-bottom profiler only briefly, reducing its received sound energy. Thus, it is unlikely that the sub-bottom profiler produces pulse levels strong enough to cause hearing impairment or other physical injuries even in an animal that is (briefly) in a position near the source.

The sub-bottom profiler is usually operated simultaneously with other higher-power acoustic sources. Many marine mammals will move away in response to the approaching higher-power sources or the vessel itself before the mammals would be close enough for there to be any possibility of effects from the sub-bottom profiler (Appendix A). In the case of mammals that do not avoid the approaching vessel and its various sound sources, mitigation measures that would be applied to minimize effects of the higher-power sources would further reduce or eliminate any minor effects of the sub-bottom profiler.

(d) Possible Effects of Pinger Signals

A pinger will be operated during all coring, to monitor the depth of the core relative to the sea floor. Sounds from the pinger are very short pulses, occurring for 0.5, 2 or 10 ms once every second, with source level ~192 dB re 1 µPa-m at a one pulse per second rate. Most of the energy in the sound pulses emitted by this pinger is at mid frequencies, centered at 12 kHz. The signal is omnidirectional. The pinger produces sounds that are within the range of frequencies used by small odontocetes and pinnipeds that occur or may occur in the area of the planned survey.

Masking

Whereas the pinger 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, marine mammal communications will not be masked appreciably by the pinger signals. This is a consequence of the relatively low power output, low duty cycle, and brief period when an individual mammal is likely to be within the area of potential effects. In the case of mysticetes, the pulses do not overlap with the predominant frequencies in the calls, which would avoid significant masking.

Behavioral Responses

Marine mammal behavioral reactions to other pulsed sound sources are discussed above, and responses to the pinger are likely to be similar to those for other pulsed sources if received at the same levels. However, the pulsed signals from the pinger are much weaker than those from the bathymetric sonars and from the airgun. Therefore, behavioral responses are not expected unless marine mammals are very close to the source.

NMFS (2001) has concluded that momentary behavioral reactions "do not rise to the level of taking". The vessel will be nearly stationary during coring, so marine mammals could be exposed to signals from the pinger for longer periods than while the vessel is underway. However, even that length of exposure would not result in a "take" by harassment because of the strength of the signal.

Hearing Impairment and Other Physical Effects

Source levels of the pinger are much lower than those of the airguns and bathymetric sonars, which are discussed above. It is unlikely that the pinger produces pulse levels strong enough to cause temporary hearing impairment or (especially) physical injuries even in an animal that is (briefly) in a position near the source.

(e) Possible Effects of Helicopter Activities

Collection of seismic refraction data requires the deployment of hydrophones at great distances from the source vessel. In order to accomplish this in the ice-covered waters of the Arctic Ocean, the science party plans to deploy SISs along seismic lines in front of the *Healy* and then retrieve them off the ice once the vessel has passed. Vessel-based helicopters will be used to shuttle SISs along seismic track lines. Deployment and recovery of SISs every 10–15 km along the track line and as far as 120 km ahead or behind the vessel will require as many as 24 on-ice landings per 24 hr period during seismic shooting.

Levels and duration of sounds received underwater from a passing helicopter are a function of the type of helicopter used, orientation of the helicopter, the depth of the marine mammal, and water depth. A civilian helicopter service will be providing air support for this project and we do not yet know what type of helicopter will be used. Helicopter sounds are detectable underwater at greater distances when the receiver is at shallow depths. Generally, sound levels received underwater decrease as the altitude of the helicopter increases (Richardson et al. 1995). Helicopter sounds are audible for much greater distances in air than in water.

Cetaceans

The nature of sounds produced by helicopter activities above the surface of the water does not pose a direct threat to the hearing of marine mammals that are in the water; however minor and short-term behavioral responses of cetaceans to helicopters have been documented in several locations, including the Beaufort Sea (Richardson et al. 1985a,b; Patenaude et al. 2002). Cetacean reactions to helicopters depend on several variables including the animal's behavioral state, activity, group size, habitat, and the flight patterns used, among other variables (Richardson et al. 1995). During spring migration in the Beaufort Sea, beluga whales reacted to helicopter noise more frequently and at greater distances than did bowhead whales (38% vs. 14% of observations, respectively). Most reaction occurred when the helicopter passed within 250 m lateral distance at altitudes ≤150 m. Neither species exhibited noticeable reactions to single passes at altitudes >150 m. Belugas within 250 m of stationary helicopters on the ice with the engine running showed the most overt reactions (Patenaude et al. 2002). Whales were observed to make only minor changes in direction in response to sounds produced by helicopters, so all reactions to helicopters were considered brief and minor. Cetacean reactions to helicopter disturbance are difficult to predict and may range from no reaction at all to minor changes in course or (infrequently) leaving the immediate area of the activity.

Pinnipeds

Few systematic studies of pinniped reactions to aircraft overflights have been completed. Documented reactions range from simply becoming alert and raising the head to escape behavior such as hauled out animals rushing to the water. Ringed seals hauled out on the surface of the ice have shown behavioral responses to aircraft overflights with escape responses most probable at lateral distances <200 m and overhead distances ≤150 m (Born et al. 1999). Although specific details of altitude and horizontal distances are lacking from many largely anecdotal reports, escape reactions to a low flying helicopter (<150 m altitude) can be expected from all four species of pinnipeds potentially encountered during the proposed operations. These responses would likely be relatively minor and brief in nature. Whether any response would occur when a helicopter is at the higher suggested operational altitudes (below) is difficult to predict and probably a function of several other variables including wind chill, relative wind chill, and time of day (Born et al. 1999).

As mentioned in the previous section, momentary behavioral reactions "do not rise to the level of taking" (NMFS 2001). In order to limit behavioral reactions of marine mammals during deployment of SISs, helicopters will maintain a minimum altitude of 200 m (656 ft) above the sea ice except when taking off or landing. Sea-ice landings within 250 m of any observed marine mammal will not occur, and the helicopter flight path will remain along the seismic track line. Three or four SIS units will be deployed/retrieved before the helicopter returns to the vessel. This should minimize the number of disturbances caused by repeated over-flights.

(f) Numbers of Marine Mammals that Might be "Taken by Harassment"

All anticipated takes would be "takes by harassment", as described in § V, involving temporary changes in behavior. The mitigation measures to be applied will minimize the possibility of injurious takes. (However, as noted earlier and in Appendix A, there is no specific information demonstrating that injurious "takes" would occur even in the absence of the planned mitigation measures.) In the sections below, we describe methods to estimate "take by harassment" and present estimates of the numbers of marine mammals that might be affected during the proposed seismic study in the Arctic Ocean. The estimates are based on data obtained during marine mammal surveys in and near the Arctic Ocean by Stirling et al. (1982), Kingsley (1986), Koski and Davis (1994), Moore et al. (2000a), and Moulton and Williams (2003), 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 take into account differences between the source data and the general 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 and/or ≥170 dB re 1 μPa (rms). The ≥160 dB criterion is applied for all species of cetaceans; the ≥170 dB criterion is applied for delphinids and pinnipeds. Based on evidence summarized in § VII(a), the 170 dB criterion is considered appropriate for those two groups, which tend to be less responsive, whereas the

160 dB criterion is considered appropriate for other cetaceans. Evidence indicates that the 160 dB criterion is suitable for summering bowhead whales (Richardson et al. 1986; Miller et al. 2005). However, during autumn some migrating bowheads have been found to react to a noise threshold closer to 130 dB re 1 μPa (rms; Miller et al. 2005; Richardson 1999).

Although several systematic surveys of marine mammals have been conducted in the southern Beaufort Sea, few data (systematic or otherwise) are available on the distribution and numbers of marine mammals in the northern Chukchi and Beaufort Seas or offshore water of the Arctic Ocean. The main sources of distributional and numerical data used in deriving the estimates are described in the next subsection. There is some uncertainty about the representativeness of those data and the assumptions used below to estimate the potential "take by harassment". However, the approach used here seems to be 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 ~3624 line kilometers of seismic surveys across the Arctic Ocean. An assumed total of 4530 km of trackline includes a 25% allowance over and above the planned ~3624 km to allow for turns, lines that might have to be repeated because of poor data quality, or for minor changes to the survey design.

The anticipated radii of influence of the bathymetric sonar, sub-bottom profiler, and pinger are less than those for the airgun configurations. It is assumed that, during simultaneous operations of all the airgun array, sonar, and profiler, any marine mammals close enough to be affected by the sonars would already be affected by the airguns. The pinger will operate only during coring while the airguns are not in operation. However, whether or not the airguns are operating simultaneously with the sonar, profiler or pinger, marine mammals are expected to exhibit no more than short-term and inconsequential responses to the sonar, profiler or pinger given their characteristics (e.g., narrow downward-directed beam) and other considerations described in § I and in § VII(b,c) above. Such reactions are not considered to constitute "taking" (NMFS 2001). Therefore, no additional allowance is included for animals that might be affected by the sound sources other than the airguns.

Basis for Estimating "Take by Harassment" for the Arctic Ocean Cruise

Numbers of marine mammals that might be present and potentially disturbed are estimated below based on available data about mammal distribution and densities in the area. The main sources of information about numbers and densities of marine mammals in the area are summarized here.

Although surveys of marine mammals have been conducted near the southern end of the proposed project area, few data are available on the species and distributions of marine mammals in the northern portions of the project area in the Arctic Ocean. No data are available on the densities of marine mammals there, although a survey through this area in August 2005 encountered few marine mammals (50 pinnipeds and 3 polar bears in 2401 km of observations between 70°N and 81°N; Haley and Ireland 2006).

The best data are from surveys in the Beaufort Sea. Moore et al. (2000a) report densities of belugas, bowheads and gray whales during summer in the Beaufort and Chukchi seas, but their densities overestimate densities for the proposed seismic survey because most bowheads and belugas are south and far to the east of the survey area during the proposed survey period, and most gray whales are southwest of it. Kingsley (1986) reported the density of ringed seals on the offshore pack ice in the central Beaufort Sea, but that density probably overestimates the density in far offshore waters where densities of ringed seals are believed to be lower than nearer to the coast. Densities of polar bears were estimated from data collected during ringed seal surveys along landfast ice in the westcentral Beaufort Sea (Moulton and Williams 2003). It is not known whether these densities are representative of densities on the offshore pack ice, particularly during late summer. In recent years, many polar bears have concentrated near bowhead harvesting sites on land during late summer.

As noted above, there is some uncertainty about the representativeness of the data and assumptions used in the calculations. Because few data were available for the northern reaches of the survey (above 75°N), we arbitrarily assigned densities based on densities observed in adjacent areas of the Beaufort Sea or northern Chukchi Sea, adjusted downward by various assumed factors (see footnotes to Tables 4 and 5). It is not known how closely the densities that were used reflect the actual densities that will be encountered; however, the approach used here is believed to be the best available at this time. Because densities of marine mammals differ between open-water and pack-ice areas, densities were calculated separately for the two regions. Images of aveage monthly sea ice concentration for August from 2000 and 2005, available from the National Snow and Ice Data Center, were used to identify 75°N as a reasonable ice-edge boundary applicable to the proposed study period and location. The "near Barrow" region is expected to consist of open water and unconsolidated pack ice during much of the cruise period. This region will include the ice margin where the highest densities of cetaceans and pinnipeds are likely to be encountered. The "polar pack" region should largely remain consolidated pack ice during the time of the cruise, and marine mammal densities are expected to be lower under those conditions.

To provide some allowance for the uncertainties, "maximum estimates" as well as "best estimates" of the numbers potentially affected have been derived (Table 6). 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, we used the available mammal survey data as the maximum estimate and assumed that the average density along the seismic trackline will be ~0.10× the density from the available survey data. The assumed densities are believed to be similar to, or in most cases higher than, the densities that will actually be encountered during the survey.

Cetaceans

Table 4 gives the average and maximum densities for each cetacean species or species group reported to occur in the Arctic Ocean north of Barrow and south of 75°N, based on the sightings and effort data from the above reports. Table 5 gives the average and maximum densities for each cetacean species or species group for the pack ice north of Barrow. Only ~8% of the planned survey will be conducted in water depths <100 m, so the densities in the table are based on surveys of offshore waters. The densities calculated from sightings during the studies have been adjusted (where needed) using correction factors from Koski et al. (1998), Thomas et al. (2002), and Barlow (1999), for both detectability and availability biases. Detectability bias, quantified in part by $f(0)$, is associated with diminishing sightability with increasing lateral distance from the 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. During surveys through the proposed study area in August of 2005 (Haley and Ireland 2006) and August 2002 (Harwood et al. 2005) no whales were observed.

The estimated numbers of potential exposures are presented below, based on the 160 dB and, for delphinids, 170 dB re 1 μPa (rms) criteria (Table 6). It is assumed that marine mammals exposed to airgun sounds that strong might change their behavior sufficiently to be considered "taken by harassment" (see § I and Table 2 for a discussion of the origin of the potential disturbance isopleths).

TABLE 4. Expected densities of marine mammals in offshore areas of the Beaufort and Chukchi seas near **Barrow, Alaska**. Except for walrus, densities are corrected for *f*(0) and *g*(0) biases. Species listed as endangered are in italics.

Species	Average Density (# / km²) [a]	Maximum Density (# / km²)
Odontocetes		
Beluga [b]	0.0034	0.0135
Narwhal	0.0000	0.0001
Delphinidae		
Killer whale	0.0000	0.0000
Phocoenidae		
Harbor porpoise [f]	0.0000	0.0002
Mysticetes		
Bowhead whale [c]	0.0032	0.0064
Gray whale [d]	0.0022	0.0045
Minke whale	0.0000	0.0000
Fin whale	0.0000	0.0000
Pinnipeds		
Walrus [i]	0.0731	0.6169
Bearded seal [e]	0.0128	0.0256
Spotted seal [g]	0.0001	0.0005
Ringed seal [f]	0.2510	1.0040
Carnivora		
Polar bear [h]	0.0016	0.0040

[a] Coefficients of variation (CVs) are not given because the density estimates come from various sources with widely differing methodologies so that CVs would not be comparable.

[b] Calculated from summer surveys of Moore et al. (2000a,b) in the Alaskan Beaufort Sea; most sightings were far to the east of the proposed seismic survey. Maximum densities are assumed to be half of the observed densities and mean densities are assumed to be 1/8th of observed densities. No beluga whales were sighted during surveys in the northern Chukchi Sea by Harwood et al. (2005), or Haley and Ireland (2006).

[c] Calculated from summer surveys of Moore et al. (2000a,b) in the Alaskan Beaufort Sea; most sightings were far to the east of the proposed seismic survey. Maximum densities are assumed to be 1/8th of the observed densities and mean densities are assumed to be 1/16th of observed densities. No bowhead whales were sighted during surveys in the northern Chukchi Sea by Brueggeman et al. (1991), Harwood et al. (2005), or Haley and Ireland (2006).

[d] Calculated from summer surveys of Moore et al. (2000b) in the Chukchi Sea; sightings only occurred near the southwest portion of the proposed seismic survey or along the coast near Pt. Barrow. Maximum densities are assumed to be 1/8th of the observed densities and mean densities are assumed to be 1/16th of observed densities and have only been applied to the southwest portion of the proposed seismic survey trackline with water depths <200 m, south of 75°N, in estimating takes (Table 6).

[e] Ringed seal density ×0.051 based on the ratio of ringed-to-bearded seals in Stirling et al. (1982).

[f] Average density is the mean pack-ice density from Kingsley (1986). Maximum density is average density ×4.

[g] There are no reliable survey data for these species in the project area. As spotted seals are known to occur in the proposed seismic survey area (primarily near Barrow) we have arbitrarily inserted densities based on their relative abundance.

[h] Estimated from sightings and effort in Moulton and Williams (2003).

[i] Average density is the average open water density from Brueggeman et al. (1990). Maximum density is the average pack ice density from Brueggeman et al. (1990). Since walruses primarily occur along the pack-ice margin in water <200m deep, these densities were applied only to the southwest portion of the proposed seismic survey trackline with water depths <200 m south of 75°N in estimating takes (Table 6).

TABLE 5. Expected densities of marine mammals in the **polar pack** ice north of Barrow. Densities are corrected for *f*(0) and *g*(0) biases. Species listed as endangered are in italics.

Species	**Average Density (# / km²) [a]**	**Maximum Density (# / km²)**
Odontocetes		
Beluga [b]	0.0003	0.0014
Narwhal	0.0000	0.0001
Mysticetes		
Bowhead whale [b]	0.0003	0.0006
Gray whale	0.0000	0.0000
Minke whale	0.0000	0.0000
Fin whale	0.0000	0.0000
Pinnipeds		
Walrus	0.0000	0.0001
Bearded seal [b]	0.0013	0.0023
Spotted seal	0.0000	0.0000
Ringed seal [b]	0.0251	0.1004
Carnivora		
Polar bear [b]	0.0002	0.0004

[a] Coefficients of variation (CVs) are not given because the density estimates come from various sources with widely differing methodologies so that CVs would not be comparable.
[b] Density is estimated as the density for the area north of Barrow/10.

Pinnipeds

In polar regions, most pinnipeds are associated with sea ice and census methods count pinnipeds when they are hauled out on ice. 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 this correction factor, the total density of the pinniped species in an area can be estimated. Only the animals in the water would be exposed to the pulsed sounds from the airguns (and sonars), and the densities that are presented generally represent all animals in the area. Therefore, only a fraction of the pinnipeds present in any given area would be exposed to seismic sounds during the proposed seismic survey.

Extensive surveys of ringed and bearded seals have been conducted in the Beaufort Sea but most surveys have been conducted over the landfast ice, and few seal surveys have been in open water or in the pack ice, where much of the proposed seismic survey will be conducted. Kingsley (1986) conducted ringed seal surveys of the offshore pack ice in the central and eastern Beaufort Sea during late spring. These surveys provide the most relevant information on densities of ringed seals there. The density estimate provided by Kingsley (1986) was used as the "average density" and this value was doubled to estimate the "maximum density" of ringed seals that may be encountered. Because no surveys have been conducted in the majority of the proposed seismic survey area, these densities in combination with

TABLE 6. Estimates of the possible numbers of marine mammal exposures to ≥160 dB and (for delphinids and pinnipeds) ≥170 dB during UTIG's proposed seismic program in the polar pack ice north of Barrow, Alaska, 15 July - 25 August, 2005. The proposed sound sources are an 8-gun array consisting of four, 500 in^3 Bolt airguns and four, 210 in^3 G. guns for a total discharge volume of 2840 in^3 and a four 105 in^3 GI gun array with a total discharge volume of 420 in^3. Received levels of airgun sounds are expressed in dB re 1 µPa (rms, averaged over pulse duration). Not all marine mammals will change their behavior when exposed to these sound levels, but some may alter their behavior when levels are lower (see text). Delphinids and pinnipeds are unlikely to react to levels below 170 dB. Species in italics are listed under the U.S. ESA as endangered. The rightmost column of numbers (in boldface) shows the numbers of "harassment takes" for which authorization is requested.

	Number of Exposures to Sound Levels ≥160 dB (≥170 dB, Less Responsive Groups)												
	Best Estimate						**Maximum Estimate**						
Species	**Barrow**		**Polar Pack**		**Total**		**Barrow**		**Polar Pack**		**Total**		**Requested Take Authorization**
Delphinidae													
Killer whale	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	0	(0)	**10**
Total Delphinidae	**0**	**(0)**	**0**	**(0)**	**0**	**(0)**	**0**	**(0)**	**0**	**(0)**	**0**	**(0)**	
Monodontidae													
Beluga	31		2		33		124		9		134		**134**
Narwhal	0		0		0		1		1		2		**5**
Phocoenidae													
Harbor porpoise	0		0		0		2		0		2		**5**
Mysticetes													
Bowhead whale	*29*		*2*		*31*		*59*		*4*		*63*		**63**
Gray whale	14		0		14		29		0		29		**29**
Minke whale	0		0		0		0		0		0		**5**
Fin whale	*0*		*0*		*0*		*0*		*0*		*0*		**5**
Total Other Cetaceans	**75**		**4**		**79**		**215**		**14**		**229**		
Pinnipeds													
Walrus	470	(143)	0	(0)	470	(143)	3960	(1203)	1	(0)	3960	(1203)	
Bearded seal	118	(47)	9	(25)	127	(72)	471	(187)	15	(45)	487	(232)	**487**
Spotted seal	1	(0)	0	(0)	1	(0)	5	(2)	0	()	5	(2)	**5**
Ringed seal	1849	(734)	135	(389)	1984	(1123)	7396	(2936)	538	(1555)	7934	(4491)	**7934**
Total Pinnipeds	**2437**	**(923)**	**143**	**(414)**	**2581**	**(1337)**	**11832**	**(4328)**	**554**	**(1599)**	**12386**	**5927**	
Carnivora													
Polar bear	15		1		16		37		0		37		

general information on ringed seal distribution and sightings from a survey through the study area in 2005 (Haley and Ireland 2006) were used for other parts of the proposed survey area (Tables 4 and 5). Haley and Ireland (2006) reported that 20% of ringed seals remained on the ice when the seismic vessel passed so estimates of numbers of ringed seals exposed to sound levels ≥170 dB re 1 µPa (rms) were reduced by this amount to account for animals that are expected to be out of the water, and hence exposed to much lower levels of seismic sounds. Densities for other common pinnipeds were estimated by multiplying ringed seal densities by the ratio of the population size of the other species to that for the ringed seal in the Beaufort Sea and adjacent areas (Tables 4 and 5).

The USFWS is currently leading a cooperative effort with other federal agencies and Russian researchers to estimate abundance of Pacific walruses. The research will use airborne thermal scanners to model the relationship between a walrus group's heat generation and the number of individuals within the group. The study effort will also address correction factors needed for animals missed because they were in the water during surveys through the use of satellite tags. There is no recent estimate of abundance for the summer population of walruses (primarily females with calves and subadults) using the Chukchi Sea. The most useful information about walruses in the Chukchi Sea area comes from surveys conducted from the mid-1970s through the 1980s over pack ice and open water areas between 156ºW and 174ºW, but to the south of the proposed *Healy* track. These reports showed walruses spread widely across the margin of the ice pack when the ice edge was between 70°N and 73ºN (Estes and Gilbert 1978; Johnson et al. 1982, Gilbert 1989). In addition, Brueggeman et al. (1990) reported walruses widespread along the ice margin between 160ºW and 165ºW when the pack ice edge was at ~73ºN. These reports restated earlier findings of Fay (1982) that walruses are seldom found far from the marginal ice edge or in regions of >80% ice coverage. With the current trend for decreasing sea ice cover in the Chukchi Sea (Tynan and DeMaster 1997; Moore and DeMaster 1997) the pack ice edge has moved farther north. Thus the proposed survey may traverse the pack ice edge where large numbers of walruses may be found.

The estimates of walrus densities most relevant to the proposed project are reported by Brueggeman et al. (1990) from seven aerial surveys of ice pack areas occurring in late June through early July. From this report, the calculated average density in open water is 0.07 walruses/km^2 and along the pack ice edge is 0.62 walruses/km^2 uncorrected for $g(0)$ or $f(0)$. These surveys took place at the southern limit of the proposed *Healy* trackline in optimal ice habitat for walruses and near the center of the northern migration concentration of the summer population of Chukchi walruses. It is along the edge of the pack ice, in ice concentrations of <80%, that the greatest densities of walruses are expected to be encountered. It is impossible to predict where the ice edge will be located during the summer of 2006. Encounters with walruses in the densities cited above are only expected along the final leg of the survey that extends southwest into the Chukchi Sea when the survey traverses the ice margin (Tables 4 and 5).

Potential Number of Cetacean "Exposures" to ≥160 and ≥170 dB

Best and Maximum Estimates of "Exposures" to ≥160 dB

The potential number of occasions when members of each species might be exposed to received levels ≥160 dB re 1 µPa (rms) was calculated for each of three water depth categories (<100 m, 100–1000 m, and >1000 m) within the two survey areas (south of 75°N "near Barrow" and north of 75°N "polar pack") by multiplying

- the expected species density, either "average" (i.e., best estimate) or "maximum", corrected as described above,

- the anticipated line-kilometers of operations with both the 4-GI and 8-airgun array in each water-depth category after applying a 25% allowance for possible additional line kilometers as noted earlier,
- the cross-track distances within which received sound levels are predicted to be ≥160 dB for each water-depth category (Table 2).

For the 8-airgun array, the cross track distance is 2 × 10,646 m for water depths of 100–1000 m, and 2 × 7,097 m for water depths >1000 m. The 8-airgun array will not be used in shallow water. The scientists propose to use the smaller array of 4 GI guns during the southern most part of the line which is in the northern Chukchi Sea where water depths are <500 m. During that part of the survey the 160 dB radius is estimated to be 6657 m in water depths <100 m and 3662 m in water depths 100-1000 m. Applying the approach described above, 43,607 km^2 would be within the 160 dB isopleth during the "near Barrow" portion of the survey. After adding the aforementioned 25% contingency to the expected number of line kilometers, the number of exposures is calculated based on 54,509 km^2. The numbers of exposures in the three depth categories were then summed for each species.

Unlike other species whose "best" and "maximum" density estimates were multiplied by the entire trackline within each of the two portions of the project area ("near Barrow" and "polar pack") to estimate exposures, gray whale and walrus densities were only multiplied by the proposed seismic trackline in water depths <200 m along the final SW leg of the survey, south of 75°N (Fig. 1). Gray whales tend to remain in the shallow, nearshore waters of the Chukchi Sea and rarely occur in the Beaufort Sea. Basing exposures on the entire SW seismic trackline south of 75°N should somewhat overestimate the number of gray whales that may be encountered while conducting seismic operations.

Based on this method, the "best" and "maximum" estimates of the numbers of marine mammal exposures to airgun sounds with received levels ≥160 dB re 1 μPa (rms) were obtained using the average and "maximum" densities from Tables 4 and 5. The estimates show that one endangered cetacean species (the bowhead whale) may be exposed to such noise levels unless bowheads avoid the approaching survey vessel before the received levels reach 160 dB. For convenience, we refer to either eventuality as an "exposure". Our respective best and maximum estimates for bowhead whales are 31 and 63, respectively (Table 6). One additional endangered cetacean species that theoretically might be encountered in the area is unlikely to be exposed. Fin whales occasionally occur near the area, but given their low "best estimates" of densities in the area, none are likely to be exposed to ≥160 dB given the planned levels of seismic survey effort in the three depth strata.

Most of the cetacean "exposures" to seismic sounds ≥160 dB would involve mysticetes (bowheads and gray whales) and monodontids (belugas). Best and maximum estimates of the number of exposures of cetaceans other than bowheads, in descending order, are beluga (33 and 134) and gray whales (14 and 29). The regional breakdown of these numbers is shown in Table 6. Estimates for other species are lower (Table 6). The far right column in Table 6, "Requested Take Authorization", shows the numbers of animals for which "harassment take authorization" is requested. For the common species, the requested numbers are calculated as indicated above, based on the assumed maximum densities as inferred from the data reported in the different studies mentioned above. In some cases, the requested numbers are somewhat higher than the maximum estimated numbers of exposures found in the second last column of Table 6. Some of the marine mammal species that are known or suspected to occur at least occasionally in arctic waters were not recorded during the limited systematic surveys used to estimate densities. In those cases, the "Requested Take Authorization" figures include upward adjustments for small numbers that might be encountered.

While migrating west, some bowhead whales displayed avoidance at distances within the received sound level of ≥130 dB (rms) during autumn seismic surveys in the Beaufort Sea (Richardson et al. 1986; Richardson 1999). It is possible that a larger number of bowhead whales than estimated may be disturbed if reactions occur at ≥130 dB (rms).

In part, because odontocete low-frequency hearing is less sensitive than that of mysticetes, odontocete reactions to seismic pulses are usually assumed to be limited to lesser distances from airguns than are those of mysticetes. However, at least when in the Canadian Beaufort Sea during the summer, belugas appear to be fairly responsive to seismic surveys. Few beluga whales were sighted within 10–20 km of seismic operations in the southeastern Beaufort Sea during aerial surveys conducted July-September 2001 (Miller et al. 2005).

Potential Number of Pinniped "Exposures" to ≥160 and ≥170 dB

As discussed above, there are few survey data that document pinniped distribution and densities within the proposed project area and no data that document their densities while they are in the water. The most relevant surveys were conducted on ringed seals in the Beaufort Sea by Kingsley (1986). Data from those surveys and information on relative population sizes for other species have been used, with various assumptions as previously described, to estimate numbers of pinnipeds that might be affected by the seismic arrays.

Ringed Seals

The ringed seal is the most widespread and abundant pinniped in ice-covered arctic waters, and there is a great deal of annual variation in population size and distribution of these marine mammals. The ringed seal accounts for the vast majority of marine mammals expected to be encountered, and hence exposed to seismic sounds ≥160 dB re 1 μPa (rms) during the proposed seismic survey. The best (and maximum) estimate is that 1984 (7934) ringed seals might be exposed to seismic sounds ≥160 dB, accounting for 91% of the marine mammals that might be so exposed. This exposure estimate assumes as many as 20% will actually be hauled out on ice where they would not be exposed to water-borne seismic sounds. In addition, the density that was used to estimate the numbers exposed was from pack ice farther south than the proposed survey area. Densities of ringed seals are expected to decline with increasing latitude, although there are no quantitative data to confirm this.

Pinnipeds are not likely to react to seismic sounds unless they are ≥170 dB re 1 μPa (rms), and many of those exposed to 170 dB also will not react overtly (Harris et al. 2001; Moulton and Lawson 2002; Miller et al. 2005). In any event, the best and maximum estimates of numbers of ringed seals that might be exposed to sounds ≥170 dB are 1123 and 4491, respectively, if 80% of seals encountered were in the water.

Pacific Walruses

Walruses are known to occur further offshore than gray whales, but generally remain in waters <200 m deep and mostly along the pack ice margin where ice concentrations are <80% (Fay 1982; Fay and Burns 1988). The location of the ice edge has shown a high degree of interannual variation, but is rarely found north of 75°N (http://nsidc.org/data/seaice_index). Exposures of walruses have been based on the assumption that 75°N will be the approximate location of the ice edge at the time the survey reaches open water in August. Calculating exposures of walruses along the entire SW seismic trackline south of 75°N should somewhat overestimate the number of exposures since concentrations of walruses are only likely to be at the proposed densities for a short distance at the margin of the ice pack. The best (and maximum) estimate of walruses that might be exposed to seismic sounds ≥160 dB is 470 (3960). Because pinnipeds are not likely to react to seismic sounds unless the received sound level is ≥170 dB re 1 μPa (rms), the best (and maximum) estimate of walruses that may be exposed to seismic sounds ≥170dB was also calculated: 143 (1203) walruses.

No correction factor for walruses hauled out on the ice (not directly exposed to the underwater seismic sounds) was applied to the exposure estimates, as was done for ringed seals. This would further overestimate the number of walruses exposed to seismic sounds ≥160 dB and ≥170dB.

Other Pinniped Species

Three other species of pinnipeds are expected to be encountered during the proposed Arctic Ocean seismic survey; one other species (harbor seal) is unlikely to be encountered, but its presence cannot be ruled out (Table 6). The species expected to be encountered are bearded seal (127 and 487, best and maximum estimates, respectively), and spotted seal (1 and 5; Table 6). Again, up to 50% of the pinnipeds that are observed hauled out on the ice are likely to stay out of the water where they will not be exposed to the full strength of the underwater seismic pulses. No adjustments were made to any pinniped exposure estimates other than ringed seals where a conservative adjustment of 20% was applied based on results from Haley and Ireland (2006). Since pinnipeds are not likely to react to seismic sounds unless they are ≥170 dB, the more relevant numbers are 72 and 232 for bearded seals, 143 and 1203 for walruses, and 0 and 2 for spotted seals. As mentioned above for ringed seals, many of these animals will be hauled out on ice, and therefore would not be exposed to the strong seismic sounds that they would be exposed to if they were in the water.

Conclusions

The proposed survey in the Arctic Ocean will involve towing two different airgun arrays that will introduce pulsed sounds into the ocean, along with simultaneous operation of a multibeam sonar and hydrographic echo sounder (sub-bottom profiler), and the use of a pinger during coring. Routine vessel operations, other than the proposed operations by the airguns, are conventionally assumed not to affect marine mammals sufficiently to constitute “taking”. For similar reasons, no “taking” is expected when the vessel is conducting scientific coring. No “taking” of marine mammals is expected in association with operations of the sonar given the considerations discussed § I and § VII(b,c), i.e., sonar sounds are beamed downward, the beam is narrow, at least in the fore-aft direction, and the pulses are extremely short.

Cetaceans

Strong avoidance reactions by several species of mysticetes to seismic vessels operating large arrays of airguns have been observed at ranges up to 6–8 km and occasionally as far as 20–30 km from the source vessel. However, reactions at the longer distances appear to be atypical of most species and situations, particularly when feeding whales are involved (Miller et al. 2005). Of the small numbers of mysticetes that will be encountered in the Arctic Ocean, many are likely to be feeding at the time of the proposed seismic survey. Furthermore, the estimated 160 and 170 dB radii used here are probably overestimates of the actual 160 and 170 dB radii at water depths ≥100 m based on the few calibration data obtained in deep water (Tolstoy et al. 2004a,b). Thus, the estimated numbers presented in Table 6 are most likely to overestimate actual numbers exposed to ≥160 and ≥170 dB (rms).

During autumn seismic surveys in the Beaufort Sea, some bowhead whales displayed avoidance upon exposure to received sound levels ≥130 dB (rms) while migrating west (Miller et al. 2005; Richardson 1999). It is possible that a larger number of bowhead whales than estimated may be disturbed if reactions occur at ≥130 dB (rms). However, bowheads that may be encountered during this planned summer project are more likely to be feeding than migrating, so the results for bowheads feeding in summer (avoidance threshold near 160 dB) are more likely to apply.

Odontocete reactions to seismic pulses are usually assumed to be limited to lesser distances from the airgun(s) than are those of mysticetes, probably in part because odontocete low-frequency hearing is less sensitive than that of mysticetes. However, at least when in the Canadian Beaufort Sea in summer, belugas appear to be fairly responsive to seismic surveys, with few being sighted within 10–20 km during aerial surveys (Miller et al. 2005).

Taking into account the moderately-sized airgun array to be used and mitigation measures that are planned, effects on cetaceans are generally expected to be restricted to avoidance of a limited area around the seismic operation and short-term changes in behavior, falling within the MMPA definition of "Level B harassment". Furthermore, the estimated numbers of animals potentially exposed to sound levels sufficient to cause appreciable disturbance are relatively low percentages of the population sizes in the Arctic Ocean, as described below.

Based on the 160 dB criterion, the *best estimates* of the numbers of *individual* cetaceans that may be exposed to sounds ≥160 dB re 1 μPa (rms) represent varying proportions of the populations of each species in the Arctic Ocean and adjacent waters (*cf.* Table 3). For species listed as "Endangered" under the ESA, our estimates include no fin whales and ~0.6% of the Bering-Chukchi-Beaufort bowhead whale population of >10,545+ (*cf.* Table 3).

Low numbers of monodontids may be exposed to sounds produced by the airgun arrays during the proposed seismic study, and the numbers potentially affected are small relative to the population sizes (Table 6). The best estimates of the numbers of belugas and narwhals that might be exposed to ≥160 dB (33 and 0, respectively) represent <1% of their populations.

Varying estimates of the numbers of marine mammals that might be exposed to sounds from the airgun arrays during the 2006 Arctic Ocean seismic survey have been presented, depending on the specific exposure criteria (≥160 vs. ≥170 dB) and density criteria used (best vs. maximum). The requested "take authorization" for each species is based on the estimated *maximum number of exposures* to ≥160 dB re 1 μPa (rms), i.e., the highest of the various estimates. That figure *likely overestimates* the actual number of animals that will be exposed to the sound levels; the reasons for this are outlined above. The relatively short-term exposures that will occur are not expected to result in any long-term negative consequences for the individuals or their populations.

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 speed, course alteration, look outs, non-pursuit, and shut 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.

Pinnipeds

A few pinniped species are likely to be encountered in the study area, but the ringed seal is by far the most abundant marine mammal that will be encountered during the seismic survey. An estimated 7934 ringed seals, 487 bearded seals, 5 spotted seals, and 3960 walruses (<1% of their Arctic Ocean and adjacent waters populations) may be exposed to airgun sounds at received levels ≥160 dB re 1 μPa (rms) during the seismic survey. It is probable that only a small percentage of those would actually be disturbed.

As for cetaceans, the short-term exposures of pinnipeds to airgun sounds are not expected to result in any long-term negative consequences for the individuals or their populations.

Polar Bears

Effects on polar bears are anticipated to be minor at most. Although the best estimate of polar bears that will be encountered during the survey is 16, almost all of these would be on the ice, and therefore they would be unaffected by underwater sound from the airguns. For the few bears that are in the water, levels of airgun and sonar sound would be attenuated because polar bears generally do not dive much below the surface. Received levels of airgun sound are reduced substantially just below the surface, relative to those at deeper depths, because of the pressure release effect at the surface.

VIII. Anticipated Impact on Subsistence

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

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. Because of the importance of subsistence, the National Science Foundation offers guidelines for science coordination with native Alaskans at http://www.arcus.org/guidelines/.

Subsistence hunting

Marine mammals are legally hunted in Alaskan waters near Barrow by coastal Alaska Natives; 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. The 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 (USDI/BLM 2005).

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 7). The communities of Nuiqsut and

TABLE 7. Bowhead landings[1] at Barrow, 1993–2004. From Burns et al. (1993), various issues of *Report of the International Whaling Commission*, Alaska Eskimo Whaling Commission, and J.C. George (NSB Dep. Wildl. Manage.), compiled by LGL Alaska (2006).

1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
23/7	16/1	20/11	24/19	31/21	25/16	24/6	18/13	26/7	20/17	16/6	21/14

[1] Numbers given are "total landings/autumn landings".

Kaktovik participate only in the fall bowhead harvest. 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 fall migration of bowhead whales that summer in the eastern Beaufort Sea typically begins in late August or September. 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 AEWC and the Barrow Whaling Captains' Association,. For this among other reasons, the project has been scheduled to commence in mid-July and terminate ~25 August, before the start of the fall hunt at Barrow (or Nuiqsut or Kaktovik), to avoid possible conflict with whalers.

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). It is possible that the timing of the proposed survey may overlap with the 2006 beluga harvest; however, the survey commences >150 km offshore, which would be well outside the area where seismic surveys would influence beluga hunting by Barrow hunters.

Ringed seals are hunted near Barrow mainly from October through June. Hunting for these smaller mammals is concentrated during winter because bowhead whales, bearded seals and caribou are available through other seasons. Winter leads in the area off Point 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 has been estimated as 394 (Table 8). Although ringed seals are available year-round, the seismic survey will not occur during the primary period when these seals are harvested. Also the seismic survey in offshore waters 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. 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; Table 8). The seismic survey will commence at least 150 km offshore from the preferred nearshore harvest area of these seals.

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) mapped the majority of bearded seal harvest sites from 1987 to 1990 as being within ~24 km of Point Barrow, well inshore of the proposed survey which is to start >150 km offshore and terminate >200 km offshore. The average annual take of bearded seals by the Barrow community from 1987 to 1990 was 174 (Table 8).

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 1995 to 2000, the average annual harvest of the Southern Beaufort Sea polar bear stock in Alaska was 32 (Angliss and Lodge 2004). That would include harvests at other smaller communities besides Barrow. It is not expected that the seismic survey will interfere with polar bear subsistence hunting due to the limited annual harvest documented by USFWS and the fact that the subsistence hunt typically takes place in the winter and spring, either well after or well before the scheduled survey.

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.) 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). It is possible, but unlikely, that accessibility to walruses during the subsistence hunt could be impaired during the *Healy's* transit north of Barrow to the starting point of the seismic survey. The area affected, however, would be an area in close proximity to the ship. The airguns would not be operating at this time.

In the event that both marine mammals and hunters were near the *Healy* when it begins operating north of Barrow, the proposed project potentially could impact the availability of marine mammals for the harvest in a very small area immediately around the *Healy*. However, the majority of marine mammals are taken by hunters within ~33 km off shore (Fig. 6), and the *Healy* will not commence the seismic survey until is significantly farther offshore (>150 km).

Helicopter operations will occur far offshore where the seismic operations take place, and thus any reactions of marine mammals to the helicopter operations will have no effects on availability of marine mammals for subsistence. Futhermore, helicopter operations will be conducted in a manner that will minimize helicopter effects on marine mammals.

TABLE 8. Average annual take of marine mammals other than bowhead whales harvested by the community of Barrow (compiled by LGL Alaska Res. Assoc. 2004).

Beluga Whales	Ringed Seals	Bearded Seals	Spotted Seals
5 **	394 *	174*	1*

* Average annual harvest for years 1987-90 (Braund et al. 1993).

** Average annual harvest for years 1962-82 (MMS 1996).

Operations off the coast of Barrow are scheduled to occur in mid-July to late August, and hunting in offshore waters generally does not occur at that time of year. (The bowhead hunt near Barrow normally does not begin until about a month later.) Considering that, and the fact that the planned seismic survey is far offshore of the hunting areas, the proposed project is not expected to have any significant impacts to the availability of marine mammals for subsistence harvest.

Subsistence fishing

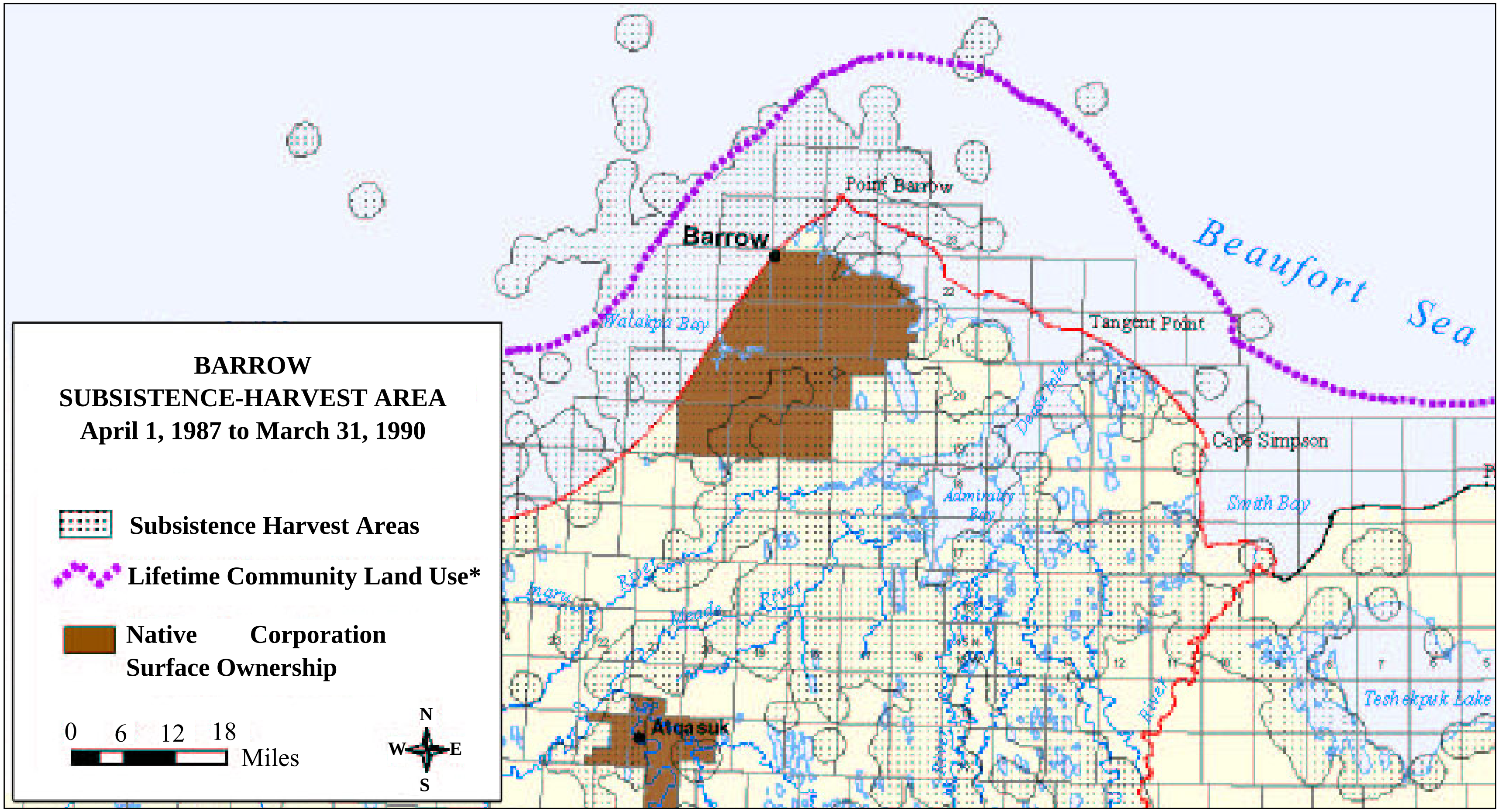
Subsistence fishing is conducted by Barrow residents through the year, but most actively during the summer and fall months. Barrow residents often fish for camp food while hunting, so the range of subsistence fishing is widespread. Marine subsistence fishing occurs during the harvest of other subsistence resources in the summer. Fishing occurs in areas much closer to Barrow and to shore than where the survey will be conducted (MMS 1996).

Seismic surveys can, at times, cause changes in the catchability of fish. Airgun operations are not planned to occur anywhere within 150 km of shore. However, in the highly unlikely event that subsistence fishing (or hunting) is occurring within 5 km (3 mi) of the Healy's trackline, the airgun operations will be suspended until the Healy is >5 km away.

IX. ANTICIPATED IMPACT ON HABITAT

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

The proposed seismic survey will not result in any permanent impact on habitats used by marine mammals, or to the food sources they utilize. Although feeding bowhead whales may occur in the area, the proposed activities will be of short duration in any particular area at any given time; thus any effects would be localized and short-term. However, the main impact issue associated with the proposed activity will be temporarily elevated noise levels and the associated direct effects on marine mammals, as discussed in § VI/VII, above.



* 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).

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.

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 only designated Essential Fish Habitiat (EFH) species that may occur in the area of the project during the seismic survey are salmon (adult), and their occurrence in waters >150 km north of the Alaska coast is highly unlikely. Adult fish near seismic operations are likely to avoid the source, thereby avoiding injury. No EFH species will be present as very early life stages when they would be unable to avoid seismic exposure that could otherwise result in minimal mortality.

The proposed Arctic Ocean seismic program for 2006 is predicted to have negligible to low physical effects on the various life stages of fish and invertebrates for its ~40 day duration and 3625-km extent. Therefore, physical effects of the proposed program on the fish and invertebrates would be not significant.

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

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

The proposed airgun operations will not result in any permanent impact on habitats used by marine mammals, or to the food sources they use. Nonetheless, 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.

During the seismic study 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. Although the main summering area for bowheads is in the Canadian Beaufort Sea, at least a few feeding bowhead whales may occur in offshore waters of the western Beaufort Sea and northern Chukchi Sea in July and August, when the *Healy* will be in the area. 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.

Thus, the proposed activity is not expected to have any habitat-related effects that could cause significant or long-term consequences for individual marine mammals or their populations, since operations at the various sites will be limited in duration.

XI. Mitigation Measures

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

For the proposed seismic survey in the Arctic Ocean, UTIG will deploy airgun sources involving 4 GI guns or 8 airguns. These sources will be small-to-moderate in size and source level, relative to airgun arrays typically used for industry seismic surveys. However, the airguns comprising the arrays will be clustered with only limited horizontal separation (Fig. 3), so the arrays will be less directional than is typically the case with larger airgun arrays. This will result in less downward directivity than is often present during seismic surveys, and more horizontal propagation of sound.

Important mitigation factors built into the design of the survey include the following:

- the project is planned for July–August, when few bowhead whales are present and no bowhead hunting is occurring;
- airgun operations will be limited to offshore waters, far from areas where there is subsistence hunting or fishing, and in waters where marine mammal densities are generally low;
- in deep offshore waters (where most of the survey will occur), sound from the airguns is expected to attenuate relatively rapidly as compared with attenuation in shallower waters;
- when operating in shallower parts of the study area, airgun operations will be limited to the smaller source (4 GI guns);
- mammal densities tend to be low in the Arctic, and that could also be seen as a mitigating factor.

In addition to these mitigation measures that are built into the general design, several specific mitigation measures will be implemented to avoid or minimize effects on marine mammals encountered along the tracklines. These include ramping up the airguns whenever they begin operations, and power-downs or shutdowns when marine mammals are detected.

Received sound fields were modeled by L-DEO for the different airgun configurations, in relation to distance and direction from the airgun(s). The radii around the airgun(s) where received levels would be 180 and 190 dB re 1 μPa (rms) depend on water depth and are shown in Table 2. The 180 and 190 dB levels are power-down or, if necessary, shut-down criteria applicable to cetaceans and pinnipeds, respectively, as specified by NMFS (2000).

Vessel-based observers will watch for marine mammals near the airgun(s) when they are in use. Mitigation and monitoring measures proposed to be implemented for the seismic survey have been developed and refined in cooperation with NMFS during previous L-DEO seismic studies and associated

EAs, IHA Applications, and IHAs. The mitigation and monitoring measures described herein represent a combination of the procedures required by past IHAs for L-DEO projects. The measures are described in detail below.

Some cetacean species (such as bowhead whales) may be feeding in the Beaufort Sea during July and August. However, the number of individual animals expected to be closely approached during the proposed activity will be small in relation to regional population sizes. With the proposed monitoring, ramp-up, power-down, and shut-down provisions (see below), any effects on individuals are expected to be limited to behavioral disturbance. That is expected to have negligible impacts on the species and stocks.

The following subsections provide more detailed information about the mitigation measures that are an integral part of the planned activity.

Marine Mammal Monitoring

Vessel-based observers will monitor marine mammals near the seismic source vessel during all airgun operations. 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.

Vessel-based observers will watch for marine mammals near the seismic vessel during all periods of shooting and for a minimum of 30 min prior to the planned start of airgun operations after an extended shut down. Due to the timing of the survey situated at high latitude, the project will take place during continuous daylight and monitoring adjustments will not be necessary for nighttime (darkness).

Proposed Safety Radii

Received sound levels were modeled by L-DEO for the different airgun configurations, in relation to distance and direction from the airguns (Fig. 3, 4). The models do not allow for bottom interactions, and are most directly applicable to deep water. Based on the model, the distances from the airguns where sound levels of 190, 180, 170, and 160 dB re 1 μPa (rms) are predicted to be received are shown Table 2.

Empirical data concerning the 180, 170 and 160 dB distances have been acquired based on measurements during the acoustic verification study conducted by L-DEO in the northern Gulf of Mexico from 27 May to 3 June 2003 (Tolstoy et al. 2004a,b). The results are limited, and do not include measurements for the sources proposed for this study. However, the data for other airgun configurations showed that water depth affected the radii around the airguns where received level would be 180 dB re 1 μPa (rms), the safety criterion applicable to cetaceans (NMFS 2000). Similar depth-related variation is likely in the 190 dB distances applicable to pinnipeds.

Water depths within the survey area are 40–3858 m, with >69% of the survey conducted in depths >1000 m. In ***deep*** (>1000 m) water, the estimated 190 and 180 dB (rms) radii for 8-airgun array are 230 and 716 m, respectively. In ***intermediate*** depths (100–1000 m), the assumed radii for the 190 and 180 dB (rms) radii in intermediate-depth water are 345 m and 1074 m, respectively, for the 8-airgun array. For operations in ***shallow*** (<100 m) water, only the 4-GI gun array would be used, and the 190 and 180 dB radii for that system operating in shallow water are assumed to be 938 m and 1822 m, respectively (Table 2). The 8-airgun array will not be used in shallow water during the proposed survey.

Airguns will be powered down (or shut down if necessary) immediately when marine mammals are detected within or about to enter the appropriate radius: 180-dB (rms) for cetaceans, and 190-dB (rms) for pinnipeds. The 180 and 190 dB shut-down criteria are consistent with guidelines listed for cetaceans and pinnipeds, respectively, by NMFS (2000) and other guidance by NMFS. UTIG, L-DEO and NSF are aware that NMFS is developing new noise-exposure guidelines, but that they have not yet been finalized or approved for use. UTIG, NSF, as well as L-DEO, will be prepared to revise their procedures for estimating numbers of mammals "taken", safety radii, etc., as may be required at some future date by the new guidelines.

Mitigation During Operations

In addition to monitoring, mitigation measures that will be adopted will include (1) speed or course alteration, provided that doing so will not compromise operational safety requirements, (2) power down or shut-down procedures, and (3) no start up of airgun operations unless the full 190 dB safety zone is visible for at least 30 min during day or night. **Note that point (3) differs from recent practice in some other projects,** in that it is here proposed that the 190 dB radius, but not necessarily the full 180 dB radius, must be visible before a ramp up can commence. The rationale for this is as follows.

Pinnipeds, to which the 190 dB safety zone applies, have not shown much avoidance of operating seismic arrays (Harris et al. 2001; Moulton and Lawson 2002, Miller et al. 2005). Therefore, it is appropriate to assume that some pinnipeds might not move out of the safety zone during a ramp up. Accordingly, the 190 dB zone should be visible before a ramp-up begins. However, the types of cetaceans likely to be encountered (bowheads and belugas) have shown avoidance of active seismic surveys and it can be expected that they will move beyond the full 180 dB radius during the ramp up. Thus, it is not critical that the full 180 dB radius applicable to cetaceans be visible prior to commencing a ramp up. During foggy conditions or darkness (which may be encountered in late August), the full 190 dB (rms) safety radius may not be visible, especially during operations in intermediate or shallow water depths. In that case, the airguns could not start up from a full shut down.

The mitigation and marine mammal monitoring measures listed and described below will be adopted during the proposed seismic program, provided that doing so will not compromise operational safety requirements:

1. Speed or course alteration;
2. Power-down procedures;
3. Shut-down procedures; and
4. Ramp-up procedures.

Speed or Course Alteration

If a marine mammal 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 science 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). However, in regions of complete ice cover, which are common north of 75°N, cetaceans are unlikely to be encountered because they must reach the surface to breathe.

Power-down Procedures

A power down involves decreasing the number of airguns in use such that the radius of the 180-dB (or 190-dB) zone is decreased to the extent that marine mammals are not in the 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 alert marine mammals to the presence of the seismic vessel in the area. In contrast, a shut down occurs when all airgun activity is suspended.

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 4- or 8-airgun array, one airgun (either a single 105 in^3 GI gun or one 210 in^3 G. gun, respectively) will be operated. If a marine mammal is detected within or near the smaller safety radius around that single airgun (see Table 2), it will be shut down as well (see next subsection).

Following a power down, airgun activity 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 small odontocetes and pinnipeds, 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. The operating airgun(s) will also be shut down completely if a marine mammal approaches or enters the estimated safety radius around the source that would 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 (small odontocetes and pinnipeds) or 30 min (mysticetes).

Ramp-up Procedures

A “ramp up” procedure will be followed when the airgun array begins operating after a specified-duration period without airgun operations. NMFS normally requires that the rate of ramp up be no more than 6 dB per 5 min period. The specified period depends on the speed of the source vessel and the size of the airgun array that is being used. Ramp up will begin with one of the G. guns (210 in^3) or one of the Bolt airguns (500 in^3) for the 8-airgun array, or one of the 105 in^3 GI guns for the 4-GI gun array. One additional airgun will be added after a period of 5 minutes. Two more airguns will be added after another 5 min, and the last four airguns (for the 8-airgun array) will all be added after the final 5 min period. During the ramp-up, the safety zone for the full airgun array in use at the time will be maintained.

If the complete 190 dB safety radius has not been visible for at least 30 min prior to the start of operations, ramp up will not commence unless at least one airgun has been operating during the interruption of seismic survey operations. This means that it will not be permissible to ramp up the 4-GI gun or 8-airgun source from a complete shut down in thick fog or darkness (which may be encountered in late August); when the outer part of the 190 dB safety zone is not visible. If the entire safety radius is visible using vessel lights and/or NVDs (as may be possible under moonlit and calm conditions), then start up of the airguns from a shut down may occur at night (if any periods of darkness are encountered during seismic operations). If one airgun has operated during a power-down period, ramp up to full power will be permissible at night or in poor visibility, on the assumption that marine mammals will be alerted to the approaching seismic vessel by the sounds from the single airgun and could move away if they choose. Ramp up of the airguns will not be initiated during the day or at night if a marine mammal has been sighted within or near the applicable safety radii during the previous 15 or 30 min, as applicable.

Helicopter flights

The use of a helicopter to deploy and retrieve SISs during the survey is expected, at most, to cause brief behavioral reactions of marine mammals. To limit disturbance to marine mammals, helicopters will follow the survey track line, avoid landing within 250 m of an observed marine mammal, and maintain a minimum altitude of 200 m. For efficiency, each helicopter excursion will be scheduled to deploy/retrieve three or four SIS units. This will minimize the number of flights and the number of potential distubances to marine mammals in the area.

XII. PLAN OF COOPERATION

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

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

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

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

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

UTIG and the AEWC will develop a "Plan of Cooperation" for the 2006 Arctic Ocean seismic survey, in consultation with representatives of the Barrow whaling community. UTIG is working with the people of Barrow to identify and avoid areas of potential conflict. Dr. Glenn Sheehan of the Barrow Arctic Science Consortium presented the proposed UTIG project at the Barrow Whaling Captains' Association's meeting 2 February. He explained the survey plans to the local residents and discussed their concerns.

The PI will present the proposed project at the AEWC's meeting which will take place 15-17 March. During that period, the PI will meet with North Slope Borough Department of Wildlife Management biologists, Robert Suydam and Craig George.

A Barrow resident knowledgeable about the mammals and fish of the area is expected to be included as a member of the MMO team aboard the *Healy*. Although his primary duties will be as a member of the MMO team responsible for implementing the monitoring and mitigation requirements, he will also be able to act as liaison with hunters and fishers if they are encountered at sea. However, the proposed activity has been timed so as to avoid overlap with the main harvests of marine mammals (especially bowhead whales), and is not expected to affect the success of subsistence fishers.

The Plan of Cooperation will cover the initial phases of UTIG's Arctic Ocean seismic survey planned to occur 15 July to 25 August. The purpose of this plan will be to identify measures that will be taken to minimize any adverse effects on the availability of marine mammals for subsistence uses, and to ensure good communication between the project scientists and the community of Barrow.

Subsequent meetings with whaling captains, other community representatives, the AEWC, NSB, and any other parties to the plan will be held as necessary to negotiate the terms of the plan and to coordinate the planned seismic survey operation with subsistence whaling activity.

The proposed Plan of Cooperation may address the following:

- Operational agreement and communications procedures
- Where/when agreement becomes effective
- General communications scheme
- On-board Inupiat observer
- Conflict avoidance
- Seasonally sensitive areas
- Vessel navigation
- Air navigation
- Marine mammal monitoring activities
- Measures to avoid impacts to marine mammals
- Measures to avoid conflicts in areas of active whaling
- Emergency assistance
- Dispute resolution process

As noted above in § IV, in the unlikely event that subsistence hunting or fishing is occurring within 5 km (3 mi) of the *Healy's* trackline, the airgun operations will be suspended until the *Healy* is >5 km away.

XIII. MONITORING AND REPORTING PLAN

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

UTIG proposes to sponsor marine mammal monitoring during the present project, in order to implement the proposed mitigation measures that require real-time monitoring, and to satisfy the anticipated monitoring requirements of the IHA.

UTIG's proposed Monitoring Plan is described below. UTIG understands that this Monitoring Plan will be subject to review by NMFS and others, and that refinements may be required.

The monitoring work described here has been planned as a self-contained project independent of any other related monitoring projects that may be occurring simultaneously in the same regions. UTIG is prepared to discuss coordination of its monitoring program with any related work that might be done by other groups insofar as this is practical and desirable.

Vessel-based Visual Monitoring

Vessel-based observers will monitor marine mammals near the seismic source vessel during all seismic operations. There will be little or no darkness during this cruise. Airgun operations will be shut down when marine mammals are observed within, or about to enter, designated safety radii (see below) where there is a possibility of significant effects on hearing or other physical effects. Vessel-based MMOs will also watch for marine mammals near the seismic vessel for at least 30 min prior to the planned start of airgun operations after an extended shut down of the airgun. When feasible, observations will also be made during daytime periods without seismic operations (e.g., during transits and during coring operations).

During seismic operations in the Arctic Ocean, four observers will be based aboard the vessel. MMOs will be appointed by UTIG with NMFS concurrence. A Barrow resident knowledgeable about the mammals and fish of the area is expected to be included as one of the team of marine mammal observers (MMOs) aboard the *Healy*. At least one observer, and when practical two observers, will monitor marine mammals near the seismic vessel during ongoing operations and nighttime start ups (if darkness is encountered in late August). Use of two simultaneous observers will increase the proportion of the animals present near the source vessel that are detected. MMO(s) will normally be on duty in shifts of duration no longer than 4 hours. The USCG crew will also be instructed to assist in detecting marine mammals and implementing mitigation requirements (if practical). Before the start of the seismic survey the crew will be given additional instruction on how to do so.

The *Healy* is a suitable platform for marine mammal observations. When stationed on the flying bridge, the eye level will be ~27.7 m (91 ft) above sea level, and the observer will have an unobstructed view around the entire vessel. If surveying from the bridge, the observer's eye level will be 19.5 m (64 ft) above sea level and ~25° of the view will be partially obstructed directly to the stern by the stack (Haley and

Ireland 2006). The MMO(s) will scan the area around the vessel systematically with reticle binoculars (e.g., 7×50 Fujinon), Big-eye binoculars (25×150), and with the naked eye. During any periods of darkness, NVDs will be available (ITT F500 Series Generation 3 binocular-image intensifier or equivalent), if and when required. The survey will take place at high latitude in the summer when there will be continuous daylight, but night (darkness) is likely to be encountered briefly at the southernmost extent of the survey in late August. Laser rangefinding binoculars (Leica LRF 1200 laser rangefinder or equivalent) will be available to assist with distance estimation; these are useful in training observers to estimate distances visually, but are generally not useful in measuring distances to animals directly.

When mammals are detected within or about to enter the designated safety radius, the airgun(s) will be powered down or shut down immediately. To assure prompt implementation of shut downs, additional channels of communication between the MMOs and the airgun technicians will be established in 2006 as compared with the arrangements on the *Healy* in 2005 (*cf.* Haley and Ireland 2006). During power downs and shut downs, the MMO(s) will continue to maintain watch to determine when the animal(s) are outside the safety radius. Airgun operations will not resume until the animal is outside 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 (small odontocetes and pinnipeds) or 30 min (mysticetes).

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

Results from the vessel-based observations will provide

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

Acoustic Monitoring

There is no plan to implement an acoustic monitoring program during the proposed seismic survey. Typically, marine mammal acoustic monitoring is conducted by listening to transmissions from a streamer or sonobuoy. Listening for marine mammal calls with a hydrophone streamer while surveying on an icebreaker would be unproductive because of masking caused by the high levels of ship noise and (when in the ice) icebreaking. Towing an additional streamer, exclusively for acoustic monitoring presents the same problems, and it is not practical to tow anything other than necessary through heavy ice. During a *Healy* seismic survey across the Arctic Ocean in 2005, transmissions from sonobouys were monitored for marine mammal vocalizations by MMOs. The sonobuoys were periodically deployed by the geophysicists to relay seismic data. The use of sonobuoys for the survey provided a convenient opportunity for the MMOs to monitor for marine mammal calls. The 2006 *Healy* survey incorporates the use of SIS units in the ice instead of sonobuoys, so the same opportunity does not present itself. Additionally, the sonobuoy monitoring effort from last year's survey was unproductive. No marine mammal vocalizations were detected during a total 98 h (739 km) of monitoring. Given these considerations, acoustic monitoring for marine mammals is not planned during the proposed survey.

Reporting

A report will be submitted to NMFS within 90 days after the end of the cruise. The report will describe the operations that were conducted and the marine mammals that were detected near the operations. The report will be submitted to NMFS, providing full documentation of methods, results, and interpretation pertaining to all monitoring. The 90-day report will summarize the dates and locations of seismic operations, and all marine mammal sightings (dates, times, locations, activities, associated seismic survey activities). The report will also include estimates of the amount and nature of potential "take" of marine mammals by harassment or in other ways. Analysis and reporting conventions will be consistent with those for the 2005 *Healy* cruise to factilitate comparisons and (where appropriate) pooling of data across the two seasons.

XIV. Coordinating Research to Reduce and Evaluate Incidental Take

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

UTIG and NSF will coordinate the planned marine mammal monitoring program associated with the seismic survey in the Arctic Ocean 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 main (northern) parts of the study area at the proposed time. However, other industry-funded seismic surveys may be occurring in the northeast Chukchi and/or western Beaufort Sea closer to shore, and those projects are likely to involve marine mammal monitoring. The monitoring contractor for this poject (LGL) is also expected to be involved in some of the industry monitoring. Further coordination of monitoring programs can occur during and after the planned Beaufort open-water peer review meeting in Anchorage in mid-April.

UTIG and NSF have coordinated, and will continue to coordinate, with other applicable Federal, State and Borough agencies, and will comply with their requirement.

- LGL has had contact with USFWS biologists of the Office of Marine Mammal Management, Anchorage, on NSF's behalf regarding potential interactions with polar bears and walruses.
- LGL has contacted the USFWS avian biologists regarding potential interaction with spectacled and Steller's eiders, birds of "concern".
- On behalf of NSF and UTIG, LGL has submitted a request to the State of Alaska confirming that the project is in compliance with state and local Coastal Management Programs.
- The Army Corps of Engineers was contacted to confirm that coring will be taking place outside of the U.S. EEZ, and therefore no permits will be required.

- The project PIs, will coordinate with the NSB Department of Wildlife Management biologists, Craig George and Robert Suydam, concerning marine mammal and fisheries issues. They plan to meet during the AEWC meeting in Anchorage in March.
- NOAA's Fisheries Biologist Larry Peltz was contacted concerning active fisheries in the study area and an EFH consultation.
- UTIG 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.

XV. LITERATURE CITED

ADFG (Alaska Department of Fish and Game). 1994. Orca: Wildlife Notebook Series. Alaska Dep. Fish & Game. Available at www.adfg.state.ak.us/pubs/notebook/marine/orca.php

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

Amstrup, S. C., G. M. Durner, I. Stirling, N. J. Lunn, and F. Messier. 2000. Movements and distribution of polar bears in the Beaufort Sea. **Can. J. Zool.** 78(6):948-966.

Amstrup, S.C., T.L. McDonald and I. Stirling. 2001. Polar bears in the Beaufort Sea: a 30-year mark-recapture case history. **J. Agric. Biol. Environ. Stat.** 6(2):221-234.

Amstrup, S.C. and D.P. DeMaster. 1988. Polar bear (*Ursus maritimus*), p. 39-56 *In*: J.W. Lentfer, (ed.) Selected marine mammals of Alaska: Species Accounts with Research and Management Recommendations. Mar. Mamm. Comm., Washington, DC.

Amstrup, S.C. and C. Gardner. 1994. Polar bear maternity denning in the Beaufort Sea. **J. Wildl. Manage.** 58(1):1-10.

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

Angliss, R.P. and K.L. Lodge. 2002. Alaska marine mammal stock assessments, 2002. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-133. 224 p.

Angliss, R.P. and K.L. Lodge. 2004. Alaska marine mammal stock assessments, 2003. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-144. 230 p.

Arbelo, M., M. Méndez, E. Sierra, P. Castro, J. Jaber, P. Calabuig, M. Carrillo and A. Fernández. 2005. Novel "gas embolic syndrome" in beaked whales resembling decompression sickness. Abstr. 16th Bien. Conf. Biol. Mar. Mamm., San Diego, CA, 12-16 Dec. 2005.

Au, W.W.L., A.N. Popper and R.R. Fay. 2000. Hearing by Whales and Dolphins. Springer-Verlag, New York, NY. 458 p.

Balcomb, K.C., III and D.E. Claridge. 2001. A mass stranding of cetaceans caused by naval sonar in the Bahamas. **Bahamas J. Sci.** 8(2):2-12.

Barlow, J. 1999. Trackline detection probability for long-diving whales. p. 209-221 *In*: G.W. Garner, S.C. Amstrup, J.L. Laake, B.F.J. Manly, L.L. McDonald and D.G. Robertson (eds.), Marine Mammal Survey and Assessment Methods. A.A. Balkema, Rotterdam. 287 p.

Bengtson, J.L., P.L. Boveng, L.M. Hiruki-Raring, K.L. Laidre, C. Pungowiyi and M.A. Simpkins. 2000. Abundance and distribution of ringed seals (*Phoca hispida*) in the coastal Chukchi Sea. p. 149-160 *In:* A.L. Lopez and D. P. DeMaster (eds.), Marine Mammal Protection Act and Endangered Species Act Implemention Program 1999. AFSC Processed Rep. 2000-11, Alaska Fish. Sci. Cent., Seattle, WA.

Bigg, M.A. 1981. Harbour seal, *Phoca vitulina* and *P. largha*. p. 1-28 *In*: S.H. Ridgway and R.J. Harrison (eds.), Handbook of Marine Mammals, Vol. 2: Seals. Academic Press, New York, NY. 359 p.

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

Boebel, O., H. Bornemann, M. Breitzke, E. Burkhardt, L. Kindermann, H. Klinck, J. Plotz, C. Ruholl and H.-W. Schenke. 2004. Risk assessment of ATLAS HYDROSWEEP DS-2 Hydrographic Deep Sea Multi-beam Sweeping Survey Echo Sounder. Poster at the International Policy Workshop on Sound and Marine Mammals, Marine Mammal Commission and Joint Nature Conservation Committee, London, 2004. Available at www.mmc.gov/sound/internationalwrkshp/pdf/poster_03boebel.pdf

Born, E.W., F.F. Riget, R. Dietz and D. Andriashek. 1999. Escape responses of hauled out ringed seals (*Phoca hispid*) to aircraft disturbance. **Polar Biol.** 21(3):171-178.

Bowles, A.E., M. Smultea, B. Würsig, D.P. DeMaster and D. Palka. 1994. Relative abundance and behavior of marine mammals exposed to transmissions from the Heard Island Feasibility Test. **J. Acoust. Soc. Am.** 96(4):2469-2484.

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

Braham, H.W. and B.D. Krogman. 1977. Population biology of the bowhead whale (*Balaena mysticetus*) and beluga (*Delphinapterus leucas*) whale in the Bering, Chukchi and Beaufort Seas. U.S. Dep. Comm., Seattle, WA.

Braham, H.W., B.D. Krogman and G.M. Carroll. 1984. Bowhead and white whale migration, distribution, and abundance in the Bering, Chukchi, and Beaufort seas, 1975-78. NOAA Tech. Rep. NMFS SSRF-778. USDOC/NOAA/NMFS. NTIS PB84-157908. 39 p.

Braund, S.R. and E.L. Moorehead. 1995. Contemporary Alaska Eskimo bowhead whaling villages. p. 253-279 *In:* A.P. McCartney (ed.), Hunting the Largest Animals/Native Whaling in the Western Arctic and Subarctic. Studies in Whaling 3. Can. Circumpolar Inst., Univ. Alberta, Edmonton, Alb. 345 p.

Braund, S.R., K. Brewster, L. Moorehead, T. Holmes and J. Kruse. 1993. North Slope subsistence study/Barrow 1987, 1988, 1989. OCS Study MMS 91-0086. Rep. from Stephen R. Braund & Assoc. and Inst. Social & Econ. Res., Univ. Alaska Anchorage. 466 p.

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

Brueggeman, J.J., C.I. Malme, R.A. Grotefendt, D.P. Volsen, J.J. Burns, D.G. Chapman, D.K. Ljungblad and G.A. Green. 1990. Shell Western E & P Inc. 1989 Walrus Monitoring Program: The Klondike, Burger, and Popcorn Prospects in the Chukchi Sea. Report prepared by EBASCO Environmental for Shell Western E & P Inc. 157 p.

Buchanan, R.A., J.R. Christian, V.D. Moulton, B. Mactavish and S. Dufault. 2004. 2004 Laurentian 2-D seismic survey environmental assessment. Rep. from LGL Ltd., St. John's, Nfld., and Canning & Pitt Associates, Inc., St. John's, Nfld., for ConocoPhillips Canada Resources Corp., Calgary, Alta. 274 p.

Burgess, W.C. and J.W. Lawson. 2000. Marine mammal and acoustic monitoring of Western Geophysical's shallow-hazards survey in the Alaskan Beaufort Sea, summer 2000. p. C-1 to C-28 *In*: W.J. Richardson (ed.), Marine mammal and acoustical monitoring of Western Geophysical's open-water seismic program in the Alaskan Beaufort Sea, 2000: 90-day report. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for Western Geophysical, Anchorage, AK, and U.S. Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 121 p.

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

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

Burns, J.J., J.J. Montague and C.J. Cowles (eds.). 1993. The bowhead whale. Spec. Publ. 2, Soc. Mar. Mamm., Lawrence, KS. 787 p.

Calambokidis, J. and S.D. Osmek. 1998. Marine mammal research and mitigation in conjunction with air gun operation for the USGS SHIPS seismic surveys in 1998. Draft rep. from Cascadia Research, Olympia, WA, for U.S. Geol. Surv., Nat. Mar. Fish. Serv., and Minerals Manage. Serv.

Caldwell, J. and W. Dragoset. 2000. A brief overview of seismic air-gun arrays. **The Leading Edge** 19(8):898-902.

Chadwick, V.J. and S. Hills. 2005. Movements of walruses radio-tagged in Bristol Bay, Alaska. **Arctic** 58(2):192-202.

Clark, J.T. and S.E. Moore. 2002. A note on observations of gray whales in the southern Chukchi and northern Bering Seas, August-November, 1980-1989. **J. Cetac. Res. Manage.** 4(3):283-288.

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

Clarke, J.T., S.E. Moore and M.M. Johnson. 1993. Observations on beluga fall migration in the Alaskan Beaufort Sea, 198287, and northeastern Chukchi Sea, 198291. **Rep. Int. Whal. Comm.** 43:387-396.

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

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

DeMaster, D.P. 1995. Minutes from the 4-5 and 11 January 1995 meeting of the Alaska Scientific Review Group. Anchorage, Alaska. 27 p. + app. Available upon request - D. P. DeMaster, Alaska Fisheries Science Center, 7600 Sand Point Way, NE, Seattle, WA 98115.

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

Derocher, A.E., D. Andriashek and J.P.Y. Arnould. 1993. Aspects of milk composition and lactation in polar bears. **Can. J. Zool.** 71(3):561-567.

Derocher, A.E., G.W. Garner, N.J. Lunn and Ø Wiig. 1998. Polar bears: Proceedings of the Twelfth Working Meeting of the IUCN/SSC Polar Bear Specialist Group, 3-7 February 1997, Oslo, Norway. Occasional Paper of the IUCN Species Survival Commission No. 19. IUCN, Gland.

Derocher, A.E., Ø. Wiig and G. Bangjord. 2000. Predation of Svalbard reindeer by polar bears. **Polar Biol.** 23(10):675-678.

DFO Canada. 2004. North Atlantic Right Whale. Fisheries and Oceans Canada. Available at http://www.mar.dfo-mpo.gc.ca/masaro/english/Species_Info/Right_Whale.html

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

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

Fay, F.H. 1981. Walrus *Odobenus rosmarus* (Linnaeus, 1758). p. 1-23 *In*: S.H. Ridgway and R.J. Harrison (eds.), Handbook of Marine Mammals, Vol. 1: The Walrus, Sea Lions, Fur Seals and Sea Otter. Academic Press, London. 235 p.

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

Fay, F.H. and J.J. Burns. 1988. Maximal feeding depth of walruses. **Arctic** 41(3):239-240.

Fay, F.H., B.P. Kelly and J.L. Sease. 1989. Managing the exploitation of Pacific walrus: a tragedy of delayed response and poor communication. **Mar. Mamm. Sci.** 5(1):1-16.

Fernández, A., M. Arbelo, E. Degollada, M. André, A. Castro-Alonso, R. Jaber, V. Martín, P. Calabuig, P. Castro, P. Herraez, F. Rodríguez and A. Espinosa de los Monteros. 2003. Pathological findings in beaked whales stranded massively in the Canary Islands (2002). p. 227-228 *In*: 17th Conf. Eur. Cetac. Soc., Las Palmas, March 2003/Conf. Guide & Abstr. European Cetacean Society.

Fernández, A., M. Arbelo, R. Deaville, I.A.P. Patterson, P. Castro, J.R. Baker, E. Degollada, H.M. Ross, P. Herráez, A.M. Pocknell, E. Rodríguez, F.E. Howie, A. Espinosa, R.J. Reid, J.R. Jaber, V.Martin, A.A. Cunningham and P.D. Jepson. 2004. Pathology: whales, sonar and decompression sickness (reply). **Nature** 428(6984).

Fernández, A., J.F. Edwards, F. Rodriquez, A.E. de los Monteros, P. Herráez, P. Castro, J.R. Jaber, V. Martin and M. Arbelo. 2005a. "Gas and fat embolic syndrome" involving a mass stranding of beaked whales (Family Ziphiidae) exposed to anthropogenic sonar signals. **Vet. Pathol.** 42(4):446-457.

Fernández, A., M. Méndez, E. Sierra, A. Godinho, P. Herráez, A.E. De los Monteros, F. Rodrigues and M. Arbelo. 2005b. New gas and fat embolic pathology in beaked whales stranded in the Canary Islands. Abstr. 16th Bien. Conf. Biol. Mar. Mamm., San Diego, CA, 12-16 Dec. 2005.

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

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

Finneran, J.J. and C.E. Schlundt. 2004. Effects of intense pure tones on the behavior of trained odontocetes. TR 1913, SSC San Diego, San Diego, CA.

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

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

Frankel, A.S. 2005. Gray whales hear and respond to a 21–25 kHz high-frequency whale-finding sonar. Abstr. 16th Bien. Conf. Biol. Mar. Mamm., San Diego, CA, 12-16 Dec. 2005.

Frantzis, A. 1998. Does acoustic testing strand whales? **Nature** 392(6671):29.

Frost, K.J. 1985. The ringed seal. Unpubl. Rep., Alaska Dep. Fish. and Game, Fairbanks, Alaska. 14 p.

Frost, K.J. and L.F. Lowry. 1981. Foods and trophic relationships of cetaceans in the Bering Sea. p. 825-836 *In*: D.W. Hood and J.A. Calder (eds.) The Eastern Bering Sea Shelf: Oceanography and Resources, Vol. 2. Univ. Wash. Press, Seattle.

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

Fuller, A.S. and J.C. George. 1999. Evaluation of subsistence harvest data from the North Slope Borough 1993 census for eight North Slope villages for the calendar year 1992. North Slope Borough, Dep. Wildl. Manage., Barrow, AK.

Gambell, R. 1985. Fin whale *Balaenoptera physalus* (Linnaeus, 1758). p. 171-192 *In*: S.H. Ridgway and R. Harrison (eds.), Handbook of Marine Mammals, Vol. 3: The Sirenians and Baleen Whales. Academic Press, London, U.K. 362 p.

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

Gentry, R. (ed.). 2002. Report of the workshop on acoustic resonance as a source of tissue trauma in cetaceans, Silver Spring, MD, April 2002. Nat. Mar. Fish. Serv. 19 p. Available at www.nmfs.noaa.gov/ prot_res/PR2/Acoustics_Program/acoustics.html

George, J.C., J. Zeh, R. Suydam and C. Clark. 2004. Abundance and population trend (1978-2001) of Western Arctic bowhead whales surveyed near Barow, Alaska. **Mar. Mamm. Sci.** 20(4):755-773.

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

Goold, J.C. 1996a. Acoustic assessment of common dolphins off the west Wales coast, in conjunction with 16th round seismic surveying. Rep. from School of Ocean Sciences, Univ. Wales, Bangor, Wales, for Chevron UK Ltd, Repsol Explor. (UK) Ltd., and Aran Energy Explor. Ltd. 22 p.

Goold, J.C. 1996b. Acoustic assessment of populations of common dolphin *Delphinus delphis* in conjunction with seismic surveying. **J. Mar. Biol. Assoc. U.K.** 76:811-820.

Goold, J.C. 1996c. Acoustic cetacean monitoring off the west Wales coast. Rep. from School of Ocean Sciences, Univ. Wales, Bangor, Wales, for Chevron UK Ltd, Repsol Explor. (UK) Ltd, and Aran Energy Explor. Ltd. 20 p.

Greene, C.R., Jr. 1997. Physical acoustics measurements. (Chap. 3, 63 p.) *In*: W.J. Richardson (ed.), 1997. Northstar Marine Mammal Marine Monitoring Program, 1996. Marine mammal and acoustical monitoring of a seismic program in the Alaskan Beaufort Sea. Rep. TA2121-2. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and U.S. Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 245 p.

Greene, C.R., Jr. and W.R. Richardson. 1988. Characteristics of marine seismic survey sounds in the Beaufort Sea. **J. Acoust. Soc. Am.** 83(6):2246-2254.

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

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

Hammill, M.O., C. Lydersen, M. Ryg and T.G. Smith. 1991. Lactation in the ringed seal (*Phoca hispida*). **Can. J. Fish. Aquatic Sci.** 48(12):2471-2476.

Harington, C.R. 1968. Denning habits of the polar bear (*Ursus maritimus*). **Can. Wildl. Serv. Rep. Ser.** 5:1-33.

Harris, R.E., G.W. Miller and W.J. Richardson. 2001. Seal responses to airgun sounds during summer seismic surveys in the Alaskan Beaufort Sea. **Mar. Mamm. Sci.** 17(4):795-812.

Harwood, J. and B. Wilson. 2001. The implications of developments on the Atlantic Frontier for marine mammals. **Cont. Shelf Res.** 21(8-10):1073-1093.

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

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

Hay, K.A. 1985. The life history of the narwhal *(Monodon monoceros* L.) in the eastern Canadian Arctic. **Diss. Abst. Int. Pt. B Sci. Eng.** 45(10).

Hay, K.A and A.W. Mansfield. 1989. Narwhal - *Monodon monoceros* Linnaeus, 1758. p. 145-176 *In*: S.H. Ridgway and R Harrison (eds.), Handbook of Marine Mammals, Vol. 4: River Dolphins and the Larger Toothed Whales. Academic Pres, London, UK.

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

Hill, P.S. and D.P. DeMaster. 1998. Draft Alaska marine mammal stock assessments 1998. U.S. Nat. Mar. Fish. Serv., Nat. Mar. Mamm. Lab., Seattle, WA.

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

Huntington, H.P. 2000. Traditional knowledge of the ecology of belugas, *Delphinapterus leucas*, in Cook Inlet, Alaska. **Mar. Fish. Rev.** 62(3):134-140.

IUCN (The World Conservation Union). 2003. 2003 IUCN Red List of Threatened Species. http://www.redlist.org

IWC. 2000. Report of the Scientific Committee from its Annual Meeting 3-15 May 1999 in Grenada. **J. Cetac. Res. Manage.** 2 (Suppl).

Jefferson, T.A., S. Leatherwood and M.A. Webber. 1993. FAO Species Identification Guide. Marine Mammals of the World. UNEP/FAO, Rome.

Jepson, P.D., M. Arbelo, R. Deaville, I.A.P. Patterson, P. Castro, J.R. Baker, E. Degollada, H.M. Ross, P. Herráez, A.M. Pocknell, F. Rodríguez, F.E. Howie, A. Espinosa, R.J. Reid, J.R. Jaber, V. Martin, A.A. Cunningham and A. Fernández. 2003. Gas-bubble lesions in stranded cetaceans. **Nature** 425(6958):575-576.

Jepson, P.D., D.S. Houser, L.A. Crum, P.L. Tyack and A. Fernández. 2005a. Beaked whales, sonar and the "bubble hypothesis". Abstr. 16th Bien. Conf. Biol. Mar. Mamm., San Diego, CA, 12-16 Dec. 2005.

Jepson, P.D. R. Deaville, I.A.P. Patterson, A.M. Pocknell, H.M. Ross, J.R. Baker, F.E. Howie, R.J. Reid, A. Colloff and A.A. Cunningham. 2005b. Acute and chronic gas bubble lesions in cetaceans stranded in the United Kingdom. **Vet. Pathol.** 42(3):291-305.

Johnson, C.B., B.E. Lawhead, J.R. Rose, M.D. Smith, A.A. Stickney and A.M. Wildman. 1999. Wildlife studies on the Colville River Delta, Alaska, 1998. Rep. from ABR, Inc., Fairbanks, AK, for ARCO Alaska, Inc., Anchorage, AK.

Johnson, A., J. Burns, W. Dusenberry and R. Jones. 1982. Aerial survey of Pacific walrus, 1980. U.S. Fish and Wildlife Service, Anchorage, AK. Mimeo report. 32 p.

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

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

Jonsgård, Å. 1966. Biology of the North Atlantic fin whale *Balaenoptera physalus* (L.): taxonomy, distribution, migration and food. **Hvalrådets Skr.** 49:1-62.

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

Keller, A.C. and L.R. Gerber. 2004. Monitoring the endangered species act: revisiting the eastern North Pacific gray whale. **Endang. Spec. Update** 21(3):87-92.

Kelly, B.P. 1988. Bearded seal, *Erignathus barbatus.* p. 77-94 *In:* J.W. Lentfer (ed.), Selected Marine Mammals of Alaska/Species Accounts with Research and Management Recommendations. Mar. Mamm. Comm., Washington, DC. 275 p.

Ketten, D.R. 1995. Estimates of blast injury and acoustic trauma zones for marine mammals from underwater explosions. p. 391-407 *In*: R.A. Kastelein, J.A. Thomas and P.E. Nachtigall (eds.), Sensory Systems of Aquatic Mammals. De Spil Publ., Woerden, Netherlands. 588 p.

Ketten, D.R., J. Lien and S. Todd. 1993. Blast injury in humpback whale ears: evidence and implications. **J. Acoust. Soc. Am.** 94(3, Pt. 2):1849-1850.

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

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

Kingsley, M.C.S. 1986. Distribution and abundance of seals in the Beaufort Sea, Amundsen Gulf, and Prince Albert Sound, 1984. Environ. Studies Revolving Funds Rep. No. 25. 16 p.

Koski, W.R. and R.A. Davis. 1994. Distribution and numbers of narwhals (*Monodon monoceros*) in Baffin Bay and Davis Strait. **Medd. Grønl., Biosci.** 39:15-40

Koski, W.R., D.H. Thomson and W.J. Richardson. 1998. Descriptions of marine mammal populations. p. 1-182 + app. *In*: Point Mugu Sea Range Marine Mammal Technical Report. Rep. from LGL Ltd., King City, ON, for Naval Air Warfare Center, Weapons Div., Point Mugu, CA, and Southwest Div. Naval Facilities Eng. Command, San Diego, CA. 322 p.

Kremser, U., P. Klemm and W.D. Kötz. 2005. Estimating the risk of temporary acoustic threshold shift, caused by hydroacoustic devices, in whales in the Southern Ocean. **Antarct. Sci.** 17(1):3-10.

Kryter, K.D. 1985. The Effects of Noise on Man, 2nd ed. Academic Press, Orlando, FL. 688 p.

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

Lentfer, W. J. 1983. Alaskan polar bear movements from mark and recovery. **Arctic** 36(3):282-288.

Lentfer, W.J., R.J. Hensel, J.R. Gilbert and F.E. Sorensen. 1980. Population characteristics of Alaskan polar bears. **Int. Conf. Bear Res. Manage.** 3:109-115.

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

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

Ljungblad, D.K., S.E. Moore and D.R. Van Schoik. 1986. Seasonal patterns of distribution, abundance, migration and behavior of the Western Arctic stock of bowhead whales, *Balaena mysticetus* in Alaskan seas. **Rep. Int. Whal. Comm., Spec. Iss.** 8:177:205.

Ljungblad, D.K., S.E. Moore, J.T. Clarke and J.C. Bennett. 1987. Distribution, abundance, behavior and bioacoustics of endangered whales in the Alaskan Beaufort and eastern Chukchi Seas, 1979-86. NOSC Tech. Rep. 1177; OCS Study MMS 87-0039. Rep. from Naval Ocean Systems Center, San Diego, CA, for U.S. Minerals Manage. Serv., Anchorage, AK. 391 p. NTIS PB88-116470.

Lowry, L. 2001. Satellite tracking of Eastern Chukchi Sea Beluga whales into the Arctic Ocean. **Arctic** 54(3):237-243.

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

Lydersen, C. and M.O. Hammill. 1993. Diving in ringed seal (*Phoca hispida*) pups during the nursing period. **Can. J. Zool.** 71(5):991-996.

MacLean, S.A. and W.R. Koski. 2005 Marine mammal monitoring during Lamont-Doherty Earth Observatory's seismic program in the Gulf of Alaska, August-September 2004. LGL Rep. TA2822-28. Rep. from LGL Ltd., King City, ON, for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 102 p.

Madsen, P.T., B. Møhl, B.K. Nielsen and M. Wahlberg. 2002. Male sperm whale behavior during exposures to distant seismic survey pulses. **Aquat. Mamm.** 28(3):231-240.

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

Malme, C.I., B. Würsig, J.E. Bird and P. Tyack. 1986. Behavioral responses of gray whales to industrial noise: feeding observations and predictive modeling. Outer Cont. Shelf Environ. Assess. Progr., Final Rep. Princ. Invest., NOAA, Anchorage, AK 56(1988):393-600. BBN Rep. 6265. 600 p. OCS Study MMS 88-0048; NTIS PB88-249008.

Malme, C.I., B. Würsig, J.E. Bird and P. Tyack. 1988. Observations of feeding gray whale responses to controlled industrial noise exposure. p. 55-73 *In*: W.M. Sackinger, M.O. Jeffries, J.L. Imm and S.D. Treacy (eds.), Port and Ocean Engineering under Arctic conditions, Vol. II. Geophysical Inst., Univ. Alaska, Fairbanks, AK. 111 p.

Manning, T.H. 1971. Geographical variation in the polar bear. **Can. Wildl. Serv. Rep. Ser. No.** 13:27 p.

Martel, V.M. n.d. Summary of the report on the atypical mass stranding of beaked whales in the Canary Islands in September 2002 during naval exercises. Society for the Study of Cetaceans in the Canary Islands.

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

McCauley, R.D., J. Fewtrell, A.J. Duncan, C. Jenner, M.N. Jenner, J.D. Penrose, R.I.T. Prince, A. Adhitya, J. Murdoch and K. McCabe. 2000a. Marine seismic surveys: Analysis of airgun signals; and effects of air gun exposure on humpback whales, sea turtles, fishes and squid. Rep. from Centre for Marine Science and Technology, Curtin Univ., Perth, W.A., for Austral. Petrol. Prod. Assoc., Sydney, N.S.W. 188 p.

McCauley, R.D., J. Fewtrell, A.J. Duncan, M.N. Jenner, C. Jenner, R.I.T. Prince, A. Adhitya, K. McCabe and J. Murdoch. 2000b. Marine seismic surveys - a study of environmental implications. **APPEA (Austral. Petrol. Product. Explor. Assoc.) Journal** 40:692-708.

McDonald, M.A., J.A. Hildebrand and S.C. Webb. 1995. Blue and fin whales observed on a seafloor array in the Northeast Pacific. **J. Acoust. Soc. Am.** 98(2, Pt.1):712-721.

Méndez, M., M. Arbelo, E. Sierra, A. Godinho, M.J. Caballero, J. Jaber, P. Herráez and A. Fernández. 2005. Lung fat embolism in cetaceans stranded in Canary Islands. Abstr. 16th Bien. Conf. Biol. Mar. Mamm., San Diego, CA, 12-16 Dec. 2005.

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

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

Mitchell, E.D. 1975. Report on the meeting on small cetaceans, Montreal, April 1-11, 1974. **J. Fish. Res. Board Can.** 32:914-91.

MMS. 1996. Beaufort Sea Planning Area oil and gas lease sale 144/Final Environmental Impact Statement. OCS EIS/EA MMS 96-0012. U.S. Minerals Manage. Serv., Alaska OCS Reg., Anchorage, AK. Two Vol. Var. pag.

Monnett, C., J.S. Gleason and L.M. Rotterman. 2005. Potential effects of diminished sea ice on open-water swimming, mortality, and distribution of polar bears during fall in the Alaskan Beaufort Sea. Abstr. 16th Bien. Conf. Biol. Mar. Mamm., San Diego, CA, 12-16 Dec. 2005.

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

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

Moore, S.E., and DeMaster, D.P. 1997. Cetacean habitats in the Alaskan Arctic. J**. Northw. Atl. Fish. Sci.** 22:55-69

Moore, S.E., J.T. Clarke and D.K. Ljungblad. 1989. Bowhead whale (*Balaena mysticetus*) spatial and temporal distribution in the central Beaufort Sea during late summer and early fall 1979-86. **Rep. Int. Whal. Comm.** 39:283-290.

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

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

Moore, S.E., J.M. Grebmeier and J.R. Davies. 2003. Gray whale distribution relative to forage habitat in the northern Bering Sea: current conditions and retrospective summary. **Can. J. Zool**. 81(4):734-742.

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

Moulton, V.D. and M.T. Williams. 2003. Incidental sightings of polar bears during monitoring activities for BP's Northstar oil development, Alaskan Beaufort Sea, 2002. Rep. from LGL Ltd. for BP Explor. (Alaska) Inc. and USFWS Office of Mar. Mamm. Manage, Anchorage, AK.

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

Nieukirk, S.L., K.M. Stafford, D.K. Mellinger, R.P. Dziak and C.G. Fox. 2004. Low-frequency whale and seismic airgun sounds recorded in the mid-Atlantic Ocean. **J. Acoust. Soc. Am.** 115(4):1832-1843.

NMFS. 2000. Small takes of marine mammals incidental to specified activities; marine seismic-reflection data collection in southern California/Notice of receipt of application. **Fed. Regist.** 65(60, 28 Mar.):16374-16379.

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

NMFS. 2002. Gray whale (*Eschrichtius robustus*): Eastern North Pacific Stock. Stock Assessment Program. Available at http://www.nmfs.noaa.gov/pr/PR2/Stock_Assessment_Program/Cetaceans/Gray_Whale_(Eastern_N._Pacific)/AK02graywhale_E.N.Pacific.PDF

NMFS. 2005. Endangered fish and wildlife; Notice of Intent to prepare an Environmental Impact Statement. **Fed. Regist.** 70(7, 11 Jan.):1871-1875.

NOAA and USN. 2001. Joint interim report: Bahamas marine mammal stranding event of 14–16 March 2000. U.S. Dep. Commer., Nat. Oceanic Atmos. Admin., Nat. Mar. Fish. Serv., Sec. Navy, Assis. Sec. Navy, Installations and Envir. 61 p.

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

Patenaude, N.J., W.J. Richardson, M.A. Smultea, W.R. Koski, G.W. Miller, B. Würsig and C.R. Greene Jr. 2002. Aircraft sound and disturbance to bowhead and beluga whales during spring migration in the Alaskan Beaufort Sea. **Mar. Mamm. Sci.** 18(2):309-335.

Pearson, W.H., J.R. Skalski and C.I. Malme. 1992. Effects of sounds from a geophysical survey device on behaviour of captive rockfish (*Sebastes* spp.). **Can. J. Fish. Aquat. Sci.** 49(7):1343-1356.

Potter, J.R. 2004. A possible mechanism for acoustic triggering of decompression sickness symptoms in deep-diving marine mammals. Paper presented to the 2004 IEEE International Symposium on Underwater Technology, Taipei, Taiwan, 19-23 April 2004. Available at http://www.zifios.com/documentos-oficiales/documentos/Singapore_John_R_Potter_UT04.pdf.

Quakenbush, L.T. 1988. Spotted seal, *Phoca largha*. p. 107-124 *In*: J.W. Lentfer (ed.), Selected Marine Mammals of Alaska/Species Accounts with Research and Management Recommendations. Marine Mammal Comm., Washington, DC. 275 p.

Ramsay, M.A. and I. Stirling. 1988. Reproductive biology and ecology of female polar bears (*Ursus maritimus*). **J. Zool.** 214:601-634.

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

Read, A.J. 1999. Harbour porpoise *Phocoena phocoena* (Linnaeus, 1758). p. 323-355 *In*: S.H. Ridgway and R. Harrison (eds.), Handbook of Marine Mammals. Vol. 6: The Second Book of Dolphins and the Porpoises. Academic Press, San Diego, CA. 486 p.

Reeves, R.R. 1980. Spitsbergen bowhead stock: a short review. **Mar. Fish. Rev.** 42(9/10):65-69.

Reeves, R.R., B.S. Stewart, P.J. Clapham and J.A. Powell. 2002. Guide to Marine Mammals of the World. Chanticleer Press, New York, NY.

Rendell, L.E. and J.C.D. Gordon. 1999. Vocal response of long-finned pilot whales (*Globicephala melas*) to military sonar in the Ligurian Sea. **Mar. Mamm. Sci.** 15(1):198-204.

Rice, D.W. and A.A. Wolman. 1971. The life history and ecology of the gray whale (*Eschrichtius robustus*). **Am. Soc. Mamm. Spec. Publ.** 3:142 p.

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

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

Richardson, W.J. and C.I. Malme. 1993. Man-made noise and behavioral responses. p. 631-700 *In:* J.J. Burns, J.J. Montague and C.J. Cowles (eds.), The Bowhead Whale. Spec. Publ. 2. Soc. Mar. Mamm., Lawrence, KS. 787 p.

Richardson, W.J. and D.H. Thomson (eds). 2002. Bowhead whale feeding in the eastern Alaskan Beaufort Sea: update of scientific and traditional information. OCS Study MMS 2002-012; LGL Rep. TA2196-7. Rep. from LGL Ltd., King City, Ont., for U.S. Minerals Manage. Serv., Anchorage, AK, and Herndon, VA. xliv + 697 p. 2 vol. NTIS PB2004-101568. Available from www.mms.gov/alaska/ref/AKPUBS.HTM#2002.

Richardson, W.J., M.A. Fraker, B. Würsig E and R.S. Wells. 1985a. Behaviour of bowhead whales, *Balaena mysticetus* , summering in the Beaufort Sea: reactions to industrial activities. **Biol. Conserv.** 32(3):185-230.

Richardson, W. J., R.S. Wells and B. Wursig. 1985b. Disturbance responses of bowheads, 1980-84. p. 89-196 *In:* W. J. Richardson (ed.), Behavior, Disturbance Responses and Distribution of Bowhead Whales *Balaena mysticetus* in the Eastern Beaufort Sea, 1980-84. OCS Study MMS 85-0034. Rep. from LGL Ecol. Res. Assoc. Inc., Bryan, TX, for U.S. Minerals, Manage. Serv., Reston, VA. 306 p. NTIS PB87-124376.

Richardson, W.J., B. Würsig and C.R. Greene. 1986. Reactions of bowhead whales, *Balaena mysticetus*, to seismic exploration in the Canadian Beaufort Sea. **J. Acoust. Soc. Am.** 79(4):1117-1128.

Richardson, W.J., R.A. Davis, C.R. Evans, D.K. Ljungblad and P. Norton. 1987. Summer distribution of bowhead whales, *Balaena mysticetus*, relative to oil industry activities in the Canadian Beaufort Sea, 1980-84. **Arctic** 40(2):93-104.

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

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

Riedman, M. 1990. The Pinnipeds: Seals, Sea Lions, and Walruses. Univ. Calif. Press, Berkeley and Los Angeles, CA. 439 p.

Rugh, D.J., K.E.W. Shelden and D.E. Withrow. 1997. Spotted seals, *Phoca largha*, in Alaska. **Mar. Fish. Rev.** 59(1):1-18.

Rugh, D.J., M.M. Muto, S.E. Moore and D.P. DeMaster. 1999. Status review of the eastern North Pacific stock of gray whales. NOAA Tech. Memo. NMFS-AFSC-103. U.S. Nat. Mar. Fish. Serv., Alaska Fish. Sci. Cent., Seattle, WA. 96 p.

Schlundt, C.E., J.J. Finneran, D.A. Carder and S.H. Ridgway. 2000. Temporary shift in masking hearing thresholds of bottlenose dolphins, *Tursiops truncatus*, and white whales, *Delphinapterus leucas*, after exposure to intense tones. **J. Acoust. Soc. Am.** 107(6):3496-3508.

Sease, J.L. and D.G. Chapman. 1988. Pacific walrus (*Odobenus rosmarus divergens*). p. 17-38 *In:* J.W. Lentfer (ed.), Selected Marine Mammals of Alaska: Species Accounts with Research and Management Recommendations. Mar. Mamm. Comm., Washington, D.C. NTIS PB88-178462.

Shaughnessy, P.D. and F.H. Fay. 1977. A review of the taxonomy and nomenclature of North Pacific harbor seals. **J. Zool. (Lond.)** 182:385-419.

Small, R. J. and D.P. DeMaster. 1995. Alaska marine mammal stock assessments 1995. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-57. 93 p.

Smith, A.E. and M.R.J. Hill. 1996. Polar bear, *Ursus maritimus*, depredation of Canada Goose, *Branta canadensis*, nests. **Can. Field-Nat.** 110(2):339-340.

Smith, T.G. 1973. Population dynamics of the ringed seal in the Canadian eastern arctic. **Fish. Res. Bo**ard **Can. Bull.** 181:55 p.

Smith, T.G. 1985. Polar Bears, *Ursus maritimus*, as predators of Belugas *Delphinapterus leucas*. **Can. Field-Nat.** 99(1):71-75.

Smith, T.G. and I. Stirling. 1975. The breeding habitat of the ringed seal (*Phoca hispida*): the birth lair and associated structures. **Can. J. Zool.** 53(9):1297-1305.

Smultea, M.A., M. Holst, W.R. Koski and S. Stoltz. 2004. Marine mammal monitoring during Lamont-Doherty Earth Observatory's seismic program in the Southeast Caribbean Sea and adjacent Atlantic Ocean, April-June 2004. LGL Rep. TA2822-26. Rep. from LGL Ltd., King City, ON, for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 106 p.

Stewart, B.S. and S. Leatherwood. 1985. Minke whale *Balaenoptera acutorostrata* Lacépède, 1804. p. 91-136 *In*: S.H. Ridgway and R. Harrison (eds.), Handbook of Marine Mammals, Vol. 3: The Sirenians and Baleen Whales. Academic Press, London, U.K. 362 p.

Stirling, I. and E.H. McEwan. 1975. The caloric value of whole ringed seals (*Phoca hispida*) in relation to polar bear (*Ursus maritimus*) ecology and hunting behavior. **Can. J. Zool.** 53(8):1021-1027.

Stirling, I., M. Kingsley and W. Calvert. 1982. The distribution and abundance of seals in the eastern Beaufort Sea, 1974-79. **Can. Wildl. Serv. Occas. Pap.** 47:25 p.

Stone, C.J. 2003. The effects of seismic activity on marine mammals in UK waters 1998-2000. JNCC Report 323. Joint Nature Conservation Committee, Aberdeen, Scotland. 43 p.

Suydam, R.S. and J.C. George. 1992. Recent sightings of harbor porpoises, *Phocoena phocoena*, near Point Barrow, Alaska. **Can. Field-Nat.** 106(4): 489-492.

Suydam, R.S., L.F. Lowry, K.J. Frost, G.M. O'Corry-Crowe and D. Pikok Jr. 2001. Satellite tracking of eastern Chukchi Sea beluga whales into the Arctic Ocean. **Arctic** 54(3):237-243.

Suydam, R.S., R.P. Angliss, J.C. George, S.R. Braund and D.P. DeMaster. 1995. Revised data on the subsistence harvest of bowhead whales (*Balaena mysticetus*) by Alaska eskimos, 1973-1993. **Rep. Int. Whal. Comm.** 45:335-338.

Swartz, S.L. and M.L. Jones. 1981. Demographic studies and habitat assessment of gray whales, *Eschrichtius robustus,* in Laguna San Ignacio, Baja California, Mexico. U.S. Mar. Mamm. Comm. Rep. MMC-78/03. 34 p. NTIS PB-289737.

Thomas, T.A., W.R. Koski and W.J. Richardson. 2002. Correction factors to calculate bowhead whale numbers from aerial surveys of the Beaufort Sea. p. 15-1 to 15-28 (Chap. 15) *In:* W.J. Richardson and D.H. Thomson (eds.), Bowhead whale feeding in the eastern Alaskan Beaufort Sea: update of scientific and traditional information, vol. 1. OCS Study MMS 2002-012; LGL Rep. TA2196-7. Rep. from LGL Ltd., King City, Ont., for U.S. Minerals Manage. Serv., Anchorage, AK, and Herndon, VA. 420 p.

Thompson, D., M. Sjöberg, E.B. Bryant, P. Lovell and A. Bjørge. 1998. Behavioural and physiological responses of harbour (*Phoca vitulina*) and grey (*Halichoerus grypus*) seals to seismic surveys. Abstr. World Mar. Mamm. Sci. Conf., Monaco.

Tolstoy, M., J. Diebold, S. Webb, D. Bohnenstiehl and E. Chapp. 2004a. Acoustic calibration measurements. Chapter 3 *In*: W.J. Richardson (ed.), Marine mammal and acoustic monitoring during Lamont-Doherty Earth Observatory's acoustic calibration study in the northern Gulf of Mexico, 2003. Revised ed. Rep. from LGL Ltd., King City, ON, for Lamont-Doherty Earth Observ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. [Advance copy of updated Chapter 3. Available at: http://www.nmfs.noaa.gov/pr/readingrm/mmpa_small_take/gom_90d_report_final.pdf

Tolstoy, M., J.B. Diebold, S.C. Webb, D.R. Bohenstiehl, E. Chapp, R.C. Holmes and M. Rawson. 2004b. Broadband calibration of R/V *Ewing* seismic sources. **Geophys. Res. Lett.** 31:L14310.

Tomilin, A.G. 1957. Mammals of the U.S.S.R. and adjacent countries, Vol. 9: Cetaceans. Israel Progr. Sci. Transl. (1967), Jerusalem. 717 p. NTIS TT 65-50086.

Treacy, S.D. 1988. Aerial surveys of endangered whales in the Beaufort Sea, fall 1987. OCS Study MMS 88-0030. U.S. Minerals Manage. Serv., Anchorage, AK. 142 p. NTIS PB89-168785.

Treacy, S.D. 1989. Aerial surveys of endangered whales in the Beaufort Sea, fall 1988. OCS Study MMS 89-0033. U.S. Minerals Manage. Serv., Anchorage, AK. 102 p. NTIS PB90-161464.

Treacy, S.D. 1990. Aerial surveys of endangered whales in the Beaufort Sea, fall 1989. OCS Study MMS 90-0047. U.S. Minerals Manage. Serv., Anchorage, AK. 105 p. NTIS PB91-235218.

Treacy, S.D. 1991. Aerial surveys of endangered whales in the Beaufort Sea, fall 1990. OCS Study MMS 91-0055. U.S. Minerals Manage. Serv., Anchorage, AK. 108 p. NTIS PB92-176106.

Treacy, S.D. 1992. Aerial surveys of endangered whales in the Beaufort Sea, fall 1991. OCS Study MMS 92-0017. U.S. Minerals Manage. Serv., Anchorage, AK. 93 p.

Treacy, S.D. 1993. Aerial surveys of endangered whales in the Beaufort Sea, fall 1992. OCS Study MMS 93-0023. U.S. Minerals Manage. Serv., Anchorage, AK. 136 p.

Treacy, S.D. 1994. Aerial surveys of endangered whales in the Beaufort Sea, fall 1993. OCS Study MMS 94-0032. U.S. Minerals Manage. Serv., Anchorage, AK. 133 p.

Treacy, S.D. 1995. Aerial surveys of endangered whales in the Beaufort Sea, fall 1994. OCS Study MMS 95-0033. U.S. Minerals Manage. Serv., Anchorage, AK. 116 p.

Treacy, S.D. 1996. Aerial surveys of endangered whales in the Beaufort Sea, fall 1995. OCS Study MMS 96-0006. U.S. Minerals Manage. Serv., Anchorage, AK. 121 p. NTIS PB97-115752

Treacy, S.D. 1997. Aerial surveys of endangered whales in the Beaufort Sea, fall 1996. OCS Study MMS 97-0016. U.S. Minerals Manage. Serv., Anchorage, AK. 115 p. NTIS PB97-194690

Treacy, S.D. 1998. Aerial surveys of endangered whales in the Beaufort Sea, fall 1997. OCS Study MMS 98-0059. U.S. Minerals Manage. Serv., Anchorage, AK. 143 p. Published 1999.

Treacy, S.D. 2000. Aerial surveys of endangered whales in the Beaufort Sea, fall 1998-1999. OCS Study MMS 2000-066. U.S. Minerals Manage. Serv., Anchorage, AK. 135 p.

Treacy, S.D. 2002a. Aerial surveys of endangered whales in the Beaufort Sea, fall 2000. OCS Study MMS 2002-014. U.S. Minerals Manage. Serv., Anchorage, AK. 111 p.

Treacy, S.D. 2002b. Aerial surveys of endangered whales in the Beaufort Sea, fall 2001. OCS Study MMS 2002-061. U.S. Minerals Manage. Serv., Anchorage, AK. 117 p.

Tyack, P., M. Johnson and P. Miller. 2003. Tracking responses of sperm whales to experimental exposures of airguns. p. 115-120 *In*: A.E. Jochens and D.C. Biggs (eds.), Sperm whale seismic study in the Gulf of Mexico/Annual Report: Year 1. OCS Study MMS 2003-069. Rep. from Texas A&M Univ., College Station, TX, for U.S. Minerals Manage. Serv., Gulf of Mexico OCS Reg., New Orleans, LA.

Tynan, C.T. and D.P. DeMaster. 1997. Observations and predictions of Arctic climate change: potential effects on marine mammals. **Arctic** 50(4):308-322.

UNEP-WCMC. 2004. UNEP-WCMC species database: CITES-listed species. Available at http://www.unep-wcmc.org/index.html?http://sea.unep-wcmc.org/isdb/CITES/Taxonomy/tax-gs-search1.cfm?displaylanguage=eng&source=animals~main

U.S. Army Corps of Engineers. 1999. Final Environmental Impact Statement, Beaufort Sea Oil and Gas Development/Northstar Project. Prepared by U.S. Army Corps of Engineers, Alaska.

USDI/MMS (U.S. Department of the Interior/Minerals Management Service). 1996. Beaufort Sea Planning Area Oil and Gas Lease Sale 144 Final Environmental Impact Statement.

USDI. 2000a. Administration of the Marine Mammal Protection Act of 1972 Annual Report, January 1, 1998 to December 31, 1998. Rep. by U.S. Fish and Wildl. Serv., and U.S. Geological Surv. Biol. Res. Division. Washington, DC.

USDI. 2000b. Administration of the Marine Mammal Protection Act of 1972 Annual Report, January 1, 1997 to December 31, 1997. Rep. by U.S. Fish and Wildl. Serv., and U.S. Geological Surv. Biol. Res. Division. Washington, DC.

USDI/BLM (U.S. Department of the Interior/Bureau of Land Management). 2003. Northwest National Petroleum Reserve – Alaska; Final Amended Integrated Activity Plan/Environmental Impact Statement.

USDI/BLM (U.S. Department of the Interior/Bureau of Land Management). 2005. Northwest National Petroleum Reserve – Alaska; Final Amended Integrated Activity Plan/Environmental Impact Statement.

USDI/MMS (U.S. Department of the Interior/Minerals Management Service). 2003. Beaufort Sea Planning Area Oil and gas lease sales 186, 195, and 202 – Final Environmental Impact Statement.

USFWS. 2000a. Pacific walrus (*Odobenus rosmarus divergens*): Alaska Stock. p. 185-190 *In*: R.C. Ferrero, D.P. DeMaster, P.S. Hill, M.M. Muto, and A.L. Lopez (eds.), Alaska Marine Mammal Stock Assessments, 2000. NOAA Tech. Memo. NMFS-AFSC-119. U.S. Dep. Comm. NOAA, NMFS, Alaska Fisheries Science Center.

USFWS. 2000b. Polar Bear: Alaska Chukchi/Bering Seas. p. 175-179 *In*: R.C. Ferrero, D.P. DeMaster, P.S. Hill, M.M. Muto, and A.L. Lopez (eds.) Alaska Marine Mammal Stock Assessments, 2000. NOAA Tech. Memo. NMFS-AFSC-119. U.S. Dep. Comm. NOAA, NMFS, Alaska Fisheries Science Center.

USFWS. 2000c. Polar bear: Alaska southern Beaufort Sea. p. 180-184 *In*: R.C. Ferrero, D.P. DeMaster, P.S. Hill, M.M. Muto, and A.L. Lopez (eds.) Alaska Marine Mammal Stock Assessments, 2000. NOAA Tech. Memo. NMFS-AFSC-119. U.S. Dep. Comm. NOAA, NMFS, Alaska Fisheries Science Center.

USFWS. 2006. Draft Study Plan for Estimating the Size of the Pacific Walrus Population. Marine Mammals Management, U.S. Fish and Wildlife Service, Alaska Science Center, U.S. Geological Survey, GiproRybFlot, Research and Engineering Institute for the Development and Operation of Fisheries, ChukotTINRO, Pacific Research Institute of Fisheries and Oceanography.

van Meurs, R. and J.F. Splettstoesser. 2003. Letter to the editor–Farthest North Polar Bear. **Arctic** 56(3):309.

Vibe, C. 1950. The marine mammals and the marine fauna in the Thule District (northwest Greenland) with observations on ice conditions in 1939-41. **Medd. Grønl.** 150:1-115.

Watkins, W.A., K.E. Moore and P. Tyack. 1985. Sperm whale acoustic behaviors in the southeast Caribbean. **Cetology** 49:1-15.

Wilson, D.E. 1976. Cranial variation in polar bears. Int. Conf. Bear Res. Manage. **IUCN Publ. New Series** 40: 447-453.

Wolfe, R. and R. Walker. 1987. Subsistence economies in Alaska: Productivity, geography and development impacts. **Arctic Anthr.** 24(2):56-81.

Woodby, D.A. and D.B. Botkin. 1993. Stock sizes prior to commercial whaling. p. 387-407 *In*: J.J. Burns, J.J. Montague and C.J. Cowles (eds.), The Bowhead Whale. Spec. Publ. 2. Soc. Mar. Mamm., Lawrence, KS. 787 p.

Yoder, J.A. 2002. Declaration of James A. Yoder in opposition to plaintiff's motion for temporary restraining order, 28 October 2002. Civ. No. 02-05065-JL. U.S. District Court, Northern District of California, San Francisco Division.

Zeh, J.E. and A.E. Punt. 2005. Updated 1978-2001 abundance estimates and their correlations for the Bering-Chukchi-Beaufort Seas stock of bowhead whales. **J. Cetac. Res. Manage.** 7(2):169-175.

Zeh, J.E., C.W. Clark, J.C. George, D. Withrow, G.M. Carroll and W.R. Koski. 1993. Current population size and dynamics. p. 409-489 *In*: J.J. Burns, J.J. Montague and C.J. Cowles (eds.), The Bowhead Whale. Spec. Publ. 2. Soc. Mar. Mamm., Lawrence, KS. 787 p.

Zeh, J.E., A.E. Raftery and A.A. Schaffner. 1996. Revised estimates of bowhead population size and rate of increase. **Rep. Int. Whal. Comm.** 46:670.

APPENDIX A:
REVIEW OF POTENTIAL IMPACTS OF AIRGUN SOUNDS ON MARINE MAMMALS [2]

The following subsections review relevant information concerning the potential effects of airgun sounds on marine mammals. This information is included here as background for the briefer summary of this topic included in § IV of the EA. This background material is little changed from corresponding subsections included in IHA applications and EAs submitted to NMFS for previous NSF-funded seismic surveys from 2003 to date. Much of this information has also been included in varying formats in other reviews, assessments, and regulatory applications prepared by LGL Ltd., environmental research associates. 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.

(a) Categories of Noise Effects

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

1. The noise may be too weak to be heard at the location of the animal, i.e., lower than the prevailing ambient noise level, the hearing threshold of the animal at relevant frequencies, or both;
2. The noise may be audible but not strong enough to elicit any overt behavioral response, i.e., the mammals may tolerate it;
3. The noise may elicit behavioral reactions of variable conspicuousness and variable relevance to the well being of the animal; these can range from subtle effects on respiration or other behaviors (detectable only by statistical analysis) to active avoidance reactions;
4. Upon repeated exposure, animals may exhibit diminishing responsiveness (habituation), or disturbance effects may persist; the latter is most likely with sounds that are highly variable in characteristics, unpredictable in occurrence, and associated with situations that the animal perceives as a threat;
5. Any man-made noise that is strong enough to be heard has the potential to reduce (mask) the ability of marine mammals to hear natural sounds at similar frequencies, including calls from conspecifics, echolocation sounds of odontocetes, and environmental sounds such as surf noise or (at high latitudes) ice noise. However, intermittent airgun or sonar pulses could cause 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 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] By **W. John Richardson** and **Valerie D. Moulton**, LGL Ltd., environmental research associates. Revised January 2006 by Meike Holst and W. John Richardson, LGL Ltd.

(b) Hearing Abilities of Marine Mammals

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

1. Absolute hearing threshold at the frequency in question (the level of sound barely audible in the absence of ambient noise). The "best frequency" is the frequency with the lowest absolute threshold.
2. Critical ratio (the signal-to-noise ratio required to detect a sound at a specific frequency in the presence of background noise around that frequency).
3. The ability to localize 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 also show that they hear and may react to many man-made sounds including sounds made during seismic exploration.

Toothed Whales

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, Mann et al. (2005) report that a Gervais' beaked whale showed evoked potentials from 5 to 80 kHz, with the best sensitivity at 80 kHz.

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, the sounds are sufficiently strong that their received levels sometimes remain above the hearing thresholds of odontocetes at distances out to several tens of kilometers (Richardson and Würsig 1997). However, there is no evidence that small odontocetes react to airgun pulses at such long distances, or even at intermediate distances where sound levels are well above the ambient noise level (see below).

The multibeam bathymetric sonars operated from oceanographic vessels to survey deep areas emit pulsed sounds at 12–15.5 kHz. Those frequencies are within or near the range of best sensitivity of many odontocetes. Thus, sound pulses from the multibeam sonar will be readily audible to these animals when they are within the narrow angular extent of the transmitted sound beam. Some vessels operate higher frequency (e.g., 24–455 kHz) multibeam sonars designed to map shallower waters, and some of those will also be audible to odontocetes.

Baleen Whales

The hearing abilities of baleen whales 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). Baleen whales also reacted to sonar sounds at 3.1 kHz and other sources centered at 4 kHz (see Richardson et al. 1995 for a review). 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, to >15 kHz (Au et al. 2001). The anatomy of the baleen whale inner ear seems to be well adapted for detection of low-frequency sounds (Ketten 1991, 1992, 1994, 2000). The absolute sound levels that they can detect below 1 kHz are probably limited by increasing levels of natural ambient noise at decreasing frequencies. Ambient noise energy is 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 sonar) sounds would be detectable and yet 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 detectable levels (Malme et al. 1984, 1988; Richardson et al. 1986, 1995; McCauley et al. 2000a; Johnson 2002).

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: 211*ff*; Kastak and Schusterman 1998, 1999; Kastelein et al. 2002). 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 (hair) 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 about 1 kHz, and range between 60 and 85 dB re 1 µPa. Measurements for a harbor seal indicate that, below 1 kHz, its thresholds deteriorate gradually to ~97 dB re 1 µPa at 100 Hz (Kastak and Schusterman 1998). The northern elephant seal appears to have better underwater sensitivity than the harbor seal, at least at low frequencies (Kastak and Schusterman 1998, 1999).

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 hair seals (harbor or elephant seal).

The underwater hearing of a walrus has been measured at frequencies from 125 Hz to 15 kHz (Kastelein et al. 2002). The range of best hearing was from 1–12 kHz, with maximum sensitivity (67 dB re 1 µPa) occurring at 12 kHz (Kastelein et al. 2002).

Sirenians

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

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

(c) Characteristics of Airgun Pulses

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 to 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 some energy up to 500–1000 Hz and above (Goold and Fish 1998). The pulsed sounds associated with seismic exploration have higher peak levels than other industrial sounds to which whales and other marine mammals are routinely exposed. The only sources with higher or comparable effective source levels are explosions.

The peak-to-peak source levels of the 2- to 20-airgun arrays used by Lamont-Doherty Earth Observatory (L-DEO) from the R/V *Maurice Ewing* during previous projects ranged from 236 to 263 dB re 1 μPa at 1 m, considering the frequency band up to about 250 Hz. The peak-to-peak source level for the 36-airgun array to be used from the *Langseth* is 265 dB. 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 numerous airguns spaced apart from one another use used. The only man-made sources with effective source levels as high as (or higher than) a large array of airguns are explosions and high-power sonars operating near maximum power.

Several important mitigating factors need to be kept in mind. *(1)* Airgun arrays produce intermittent sounds, involving emission of a strong sound pulse for a small fraction of a second followed by several seconds of near silence. In contrast, some other sources produce sounds with lower peak levels, but their sounds are continuous or discontinuous but continuing for much 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. 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 levels, in bar-meters or (less often) dB re 1 μPa · m. The peak (= zero-to-peak) level for the same pulse is typically about 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 about 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 sometimes used is the energy, or Sound Exposure Level (SEL), in dB re 1 $\mu Pa^2 \cdot s$. Because the pulses are <1 s in duration, the numerical value of the energy is lower than the rms pressure level, but the units are different. 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, NMFS has commonly referred to rms levels when discussing levels of pulsed sounds that might "harass" marine mammals.

Seismic sound 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 about 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 about 300 ms at a distance of 8 km, 500 ms at 20 km, and 850 ms at 73 km (Greene and Richardson 1988).

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). 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 at 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 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). Considerably higher levels can occur at distances out to several kilometers from an operating airgun array.

(d) Masking Effects of Seismic Surveys

Masking effects of pulsed sounds on marine mammal calls and other natural sounds are expected to be limited, although there are few specific data on this. 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 ceased calling when exposed to pulses from a very distant seismic ship (Bowles et al. 1994), more recent studies reported that sperm whales continued calling in the presence of seismic pulses (Madsen et al. 2002; Tyack et al. 2003). 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 airgun sounds.

Most of the energy in the sound pulses emitted by airgun arrays is at low frequencies, with strongest spectrum levels below 200 Hz and considerably lower spectrum levels above 1000 Hz. These low frequencies are mainly used by mysticetes, but generally not by odontocetes, pinnipeds, or sirenians.

An industrial sound source will reduce the effective communication or echolocation distance only if its frequency is close to that of the marine mammal signal. If little or no overlap occurs between the industrial noise and the frequencies used, as in the case of many marine mammals vs. airgun sounds, communication and echolocation are not expected to be disrupted. Furthermore, the discontinuous nature of seismic pulses makes significant masking effects unlikely even for mysticetes.

A few cetaceans are known to increase the source levels of their calls in the presence of elevated sound levels, or to shift their peak frequencies in response to strong sound signals (Dahlheim 1987; Au 1993; Lesage et al. 1999; Terhune 1999; Nieukirk et al. 2005; Parks et al. 2005; reviewed in Richardson et al. 1995:233*ff*, 364*ff*). These studies involved exposure to other types of anthropogenic sounds, not seismic pulses, and it is not known whether these types of responses ever occur upon exposure to seismic sounds. If so, these adaptations, along with directional hearing and preadaptation to tolerate some masking by natural sounds (Richardson et al. 1995), would all reduce the importance of masking.

(e) Disturbance by Seismic Surveys

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

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

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

Based on this guidance from NMFS, 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".

Even with this guidance, there are difficulties in defining what marine mammals should be counted as "taken by harassment". For many species and situations, we do not have detailed information about their reactions to noise, including reactions to seismic (and sonar) pulses. Behavioral reactions of marine mammals to sound are difficult to predict. 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 to an underwater sound by changing its behavior or moving a small distance, the impacts of the change may not 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. In most cases, this likely overestimates the numbers of marine mammals that are affected in some biologically important 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 species and sound types. In 2005, public meetings were conducted across the nation to consider the impact of implementing new criteria for what constitutes a "take" of marine mammals. Currently, a committee of specialists on noise impact issues is drafting recommendations for new impact criteria, as summarized by Gentry et al. (2004); those recommendations are expected to be made public soon. 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-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, and small toothed whales.

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 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, 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. Some studies and reviews on this topic are as follows: 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; Miller et al. 1999; 2005; Gordon et al. 2004; Moulton and Miller in press). There is also evidence that baleen whales will often show avoidance of a small airgun source or upon onset of a ramp up when just one airgun is firing. 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, 1987, 1988; Richardson et al. 1986; McCauley et al. 1998, 2000a,b)

Prior to the late 1990s, it was thought that bowhead, gray, and humpback whales all begin to show strong avoidance reactions to seismic pulses at received levels of ~160 to 170 dB re 1 μPa rms, but that subtle behavioral changes sometimes become evident at somewhat lower received levels. More recent studies have shown that some species of baleen whales (bowheads and humpbacks in particular) may show strong avoidance at received levels lower than 160–170 dB re 1 μPa rms. The observed avoidance reactions involved movement away from feeding locations or statistically significant deviations in the whales' direction of swimming and/or migration corridor as they approached or passed the sound sources. In the case of the migrating 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.

Humpback Whales.—McCauley et al. (1998, 2000a) studied the responses of humpback whales off Western Australia to a full-scale seismic survey with a 16-airgun 2678-in^3 array, and to a single 20 in^3

airgun with source level 227 dB re 1 μPa·m (p-p). They found that the overall distribution of humpbacks migrating through their study area was unaffected by the full-scale seismic program. McCauley et al. (1998) did, however, document localized avoidance of the array and of the single airgun. Avoidance reactions began at 5–8 km from the array, and those reactions kept most pods about 3–4 km from the operating seismic boat. Observations were made from the seismic vessel, from which the maximum viewing distance was listed as 14 km. Avoidance distances with respect to the single airgun were smaller but consistent with the results from the full array in terms of the received sound levels. Mean avoidance distance from the airgun corresponded to a received sound level of 140 dB re 1 μPa rms; this was the level at which humpbacks started to show avoidance reactions to an approaching airgun. The standoff range, i.e., the closest point of approach (CPA) of the airgun to the whales, corresponded to a received level of 143 dB 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 100–400 m, where the maximum received level was 179 dB re 1 μPa rms.

Humpback whales summering 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.

Bowhead Whales.—Bowhead whales on their summering 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). 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. This work and a more recent study by Miller et al. (2005) show that feeding bowhead whales tend to tolerate higher sound levels than migrating bowhead whales before showing an overt change in behavior. The feeding whales may be affected by the sounds, but the need to feed may reduce the tendency to move away.

Migrating bowhead whales in the Alaskan Beaufort Sea seem more responsive to noise pulses from a distant seismic vessel than are summering bowheads. In 1996–98, 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 (Miller et al. 1999; Richardson et al. 1999). Aerial surveys showed that some westward-migrating whales avoided an active seismic survey boat by 20–30 km, and that few bowheads approached within 20 km. Received sound levels at those distances were only 116–135 dB re 1 μPa (rms). Some whales apparently began to deflect their migration path when still as much as ~35 km away from the airguns. 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.

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 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. 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 (0-pk) in the northern Bering Sea. These findings were generally consistent with the results of experiments conducted on larger numbers of gray whales that were migrating along the California coast. Malme and Miles (1985) concluded that, during migration, changes in swimming pattern occurred for received levels of about 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 array operating off central California. This would occur at an average received sound level of about 170 dB (rms). Some slight behavioral changes were noted at received sound levels of 140 to 160 dB (rms).

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. However, there were indications of subtle behavioral effects and (in 2001) localized avoidance by some individuals (Johnson 2002; Weller et al. 2002).

Rorquals.—Blue, sei, fin, and minke whales have occasionally been reported in areas ensonified by airgun pulses. Sightings by observers on seismic vessels off the U.K. from 1997 to 2000 suggest that, at times of good sightability, numbers of rorquals seen are similar when airguns are shooting and not shooting (Stone 2003). Although individual species did not show any significant displacement in relation to seismic activity, all baleen whales combined were found to remain significantly further from the airguns during shooting compared with periods without shooting (Stone 2003). Baleen whale pods sighted from the ship were found to be at a median distance of ~1.6 km from the array during shooting and 1.0 km during periods without shooting (Stone 2003). Baleen whales, as a group, made more frequent alterations of course (usually away from the vessel) during shooting compared with periods of no shooting (Stone 2003). In addition, fin/sei whales were less likely to remain submerged during periods of seismic shooting (Stone 2003).

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 humpback and especially migrating bowhead whales, show that reactions, including avoidance, 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 are biased.

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 4.5 to 14.5 km from the source. A substantial proportion of the baleen whales within this distance range may show avoidance or other strong disturbance reactions to the operating airgun array. In the case of migrating bowhead whales, avoidance extends to larger distances and lower received sound levels.

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. 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. Bowheads were often seen in summering areas where seismic exploration occurred in preceding summers (Richardson et al. 1987). They also have been observed over periods of days or weeks in areas repeatedly ensonified by seismic pulses. However, it is not known whether the same individual bowheads were involved in these repeated observations (within and between years) in strongly ensonified areas.

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, and none similar in size and scope to the studies of humpback, bowhead, and gray whales mentioned above. However, systematic work on sperm whales is underway.

Delphinids.—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 operating seismic vessels (e.g., Stone 2003; Moulton and Miller in press). Studies that have reported cases of small toothed whales close to the operating airguns include Duncan (1985), Arnold (1996), and Stone (2003). 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). Most, but not all, dolphins often seemed to be attracted to the seismic vessel and floats, and some rode the bow wave of the seismic vessel regardless of whether the airguns were firing.

Goold (1996a,b,c) studied the effects on common dolphins, *Delphinus delphis*, of 2D seismic surveys in the Irish Sea. Passive acoustic surveys were conducted from the "guard ship" that towed a hydrophone 180-m aft. 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).

A monitoring study of summering belugas exposed to a seismic survey found that sighting rates, as determined by aerial surveys, were significantly lower at distances of 10–20 compared with 20–30 km from the operating airgun array (Miller et al. 2005). The low number of sightings from the vessel seemed to confirm a large avoidance response to the 2250 in^3 airgun array. The apparent displacement effect on belugas extended farther than has been shown for other small odontocetes exposed to airgun pulses.

Observers stationed on seismic vessels operating off the United Kingdom from 1997–2000 have provided data on the occurrence and behavior of various toothed whales exposed to seismic pulses (Stone 2003; Gordon et al. 2004). 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 of shooting. Except for pilot whales, all of the small odontocete species tested, including killer whales, were found to be significantly farther from large airgun arrays during periods of shooting compared with periods of no shooting. Pilot whales showed few reactions to seismic activity. The displacement of the median distance from the array was ~0.5 km or more for most species groups. Killer whales appeared to be more tolerant of seismic shooting in deeper waters.

For all small odontocete species, except pilot whales, that were sighted during seismic surveys off the U.K. in 1997–2000, the numbers of positive interactions with the survey vessel (e.g., bow-riding, approaching the vessel) were significantly fewer during periods of shooting. All small odontocetes combined showed more negative interactions (e.g., avoidance) during periods of shooting. Small odontocetes, including white-beaked dolphins, *Lagenorhynchus* spp., and other dolphin species, showed a tendency to swim faster during periods with seismic shooting; *Lagenorhynchus* spp. were also observed to swim more slowly during periods without shooting. Significantly fewer white-beaked dolphins, *Lagenorhynchus* spp. and pilot whales traveled towards the vessel and/or more were traveling away from the vessel during periods of shooting.

During two NSF-funded L-DEO seismic surveys, using 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). Monitoring results during a seismic survey in the Southeast Caribbean showed that the mean CPA of delphinids during seismic operations was 991 m compared with 172 m when the airguns were not operational (Smultea et al. 2004). Surprisingly, nearly all acoustic encounters (including 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 of delphinids during seismic operations was 472 m compared with 178 m when the airguns were not operational (Holst et al. 2005a). The acoustic detection rates were nearly 5 times higher during non-seismic compared with seismic operations (Holst et al. 2005a).

Reactions of toothed whales to a single airgun or other small airgun source are not well documented, but do not seem to be very substantial (e.g., Stone 2003). Results from three NSF-funded L-DEO seismic surveys using small arrays (up to 3 GI guns and 315 in^3) were inconclusive. During a survey in the Eastern Tropical Pacific (Holst et al. 2005b) and in the Northwest Atlantic (Haley and Koski 2004), detection rates were slightly lower during seismic compared to non-seismic periods. However, mean CPAs were closer during seismic 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 small-array survey in southeast Alaska were even more variable (MacLean and Koski 2005).

Captive bottlenose dolphins and beluga whales exhibited changes in behavior when exposed to strong pulsed sounds similar in duration to those typically used in seismic surveys (Finneran et al. 2000, 2002). Finneran et al. (2002) exposed a captive bottlenose dolphin and beluga to single impulses from a water gun (80 in^3). As compared with airgun pulses, water gun impulses were expected to contain proportionally more energy at higher frequencies because there is no significant gas-filled bubble, and thus little low-frequency bubble-pulse energy (Hutchinson and Detrick 1984). The captive animals sometimes vocalized after exposure and exhibited reluctance to station at the test site where subsequent exposure to impulses would be implemented (Finneran et al. 2002). Similar behaviors were exhibited by captive bottlenose dolphins and a beluga exposed to single underwater pulses designed to simulate those produced by distant underwater explosions (Finneran et al. 2000). It is uncertain what relevance these observed behaviors in captive, trained marine mammals exposed to single sound pulses may have to free-ranging animals exposed to multiple pulses. In any event, the animals tolerated rather high received levels of sound (pk-pk level >200 dB re 1 μPa) before exhibiting the aversive behaviors mentioned above.

Observations of odontocete responses (or lack of responses) to noise pulses from underwater explosions (as opposed to airgun pulses) may be relevant as an indicator 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 temporary threshold shift (TTS), the tolerance to these charges may indicate a lack of effect or the failure to move away may simply indicate a stronger desire to eat, regardless of circumstances.

Phocinids.—Porpoises, like delphinids, show variable reactions to seismic operations. Calambokidis and Osmek (1998) noted that Dall’s porpoises observed during a survey with a 6000 in^3, 12–16-airgun array tended to head away from the boat. Similarly, during seismic surveys off the U.K. in 1997–2000, significantly fewer harbor porpoises traveled towards the vessel and/or more were traveling away from the vessel during periods of shooting (Stone 2003). During both an experimental and a commercial seismic survey, Gordon et al. (1998 *in* Gordon et al. 2004) noted that acoustic contact rates for harbor porpoises were similar during seismic and non-seismic periods.

Beaked Whales.—There are 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). It is likely that these beaked whales would normally show strong avoidance of an approaching seismic vessel, but this has not been documented explicitly. Northern bottlenose whales sometimes are quite tolerant of slow-moving vessels (Reeves et al. 1993; Hooker et al. 2001). However, those vessels were not emitting airgun pulses.

There are increasing indications that some beaked whales tend to strand when naval exercises, including sonar operation, are ongoing nearby (e.g., Simmonds and Lopez-Jurado 1991; Frantzis 1998; NOAA and USN 2001; Jepson et al. 2003; see also the “Strandings and Mortality” subsection, later). These strandings are apparently at least in part a disturbance response, although auditory or other injuries 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. There was a stranding of Cuvier’s beaked whales in the Gulf of California (Mexico) in Sept. 2002 when the R/V *Maurice Ewing* was conducting a seismic survey in the general area (e.g., Malakoff 2002). Another stranding of Cuvier’s beaked whales in the Galapagos 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). The evidence with respect to seismic surveys and beaked whale strandings is inconclusive, and NMFS has not established a link between the Gulf of California stranding and the seismic activities (Hogarth 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). Thus, it is to be expected that they would tend to avoid an operating seismic survey vessel. There are some 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 (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, sperm whales in the Gulf of Mexico may have moved away from a seismic vessel (Mate et al. 1994).

On the other hand, recent (and more extensive) data from vessel-based monitoring programs in U.K. waters suggest that sperm whales in that area show little evidence of avoidance or behavioral disruption in the presence of operating seismic vessels (Stone 2003). These types of observations are difficult to interpret because the observers are stationed on or near the seismic vessel, and may under-estimate reactions by some of the more responsive species or individuals, which may be beyond visual range. However, the U.K. results do seem to show considerable tolerance of seismic surveys by at least some sperm whales. Also, a recent 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 pk-pk (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). An experimental study of sperm whale reactions to seismic surveys in the Gulf of Mexico is presently underway (Caldwell 2002; Jochens and Biggs 2003), along with a study of the movements of sperm whales with satellite-linked tags in relation to seismic surveys (Mate 2003). During two controlled exposure experiments where sperm whales were exposed to seismic pulses at received levels 143–148 dB re 1 μPa, there was no indication of avoidance of the vessel or changes in feeding efficiency (Jochens and Biggs 2003). The received sounds were measured on an "rms over octave band with most energy" basis (P. Tyack, pers. comm.); the broadband rms value would be somewhat higher. Although the sample size from the initial work was small (four whales during two experiments), the results are consistent with those off northern Norway.

Conclusions.—Dolphins and porpoises are often seen by observers on active seismic vessels, occasionally at close distances (e.g., bow riding). However, some studies, especially near the U.K., show localized avoidance. Belugas summering in the Beaufort Sea tended to avoid waters out to 10–20 km from an operating seismic vessel. In contrast, recent studies show little evidence of reactions by sperm whales to airgun pulses, contrary to earlier indications.

There are 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.

Pinnipeds

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

Early observations provided considerable evidence that pinnipeds are often quite tolerant of strong pulsed sounds. During seismic exploration off Nova Scotia, grey 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 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 has demonstrated short-term changes in the behavior of harbor (=common) seals and grey seals exposed to airgun pulses (Thompson et al. 1998). In this study, 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. All grey seals exposed to a single 10 in^3 airgun showed an avoidance reaction. Seals 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 all grey 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).

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). These seismic projects usually involved arrays of 6–16 airguns with total volumes 560–1500 in^3. The combined results suggest that some seals avoid the immediate area around seismic vessels. In most survey years, ringed seal sightings tended to be farther away from the seismic vessel when the airguns were operating then when they were not (Moulton and Lawson 2002). However, these 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. Seal sighting rates at the water surface were lower during airgun array operations than during no-airgun periods in each survey year except 1997.

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 array (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 behav-iors, 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 2001-02 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 were seen closer to the vessel during non-seismic than seismic periods. In contrast, during 2002, sighting rates of seals were higher during non-seismic periods than seismic operations, and seals were seen farther from the vessel during non-seismic compared to seismic activity (a marginally significant result). The combined data for both years showed that sighting rates were higher during non-seismic periods compared to seismic periods, and that sighting distances were similar during both seismic states. Miller et al. (2005) concluded that seals showed very limited avoidance to the operating airgun array.

In summary, visual monitoring from seismic vessels has shown only slight (if any) avoidance of airguns by pinnipeds, and only slight (if any) changes in behavior. These studies show that pinnipeds frequently do not avoid the area within a few hundred meters of an operating airgun array. However, initial telemetry work suggests that avoidance and other behavioral reactions may be stronger than evident to date from visual studies.

Fissipeds.—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 array. No disturbance reactions were evident when the airgun array was as close as 0.9 km. Otters also did not respond noticeably to the single airgun. The results suggest that sea otters may be less responsive to marine seismic pulses than other marine mammals. Also, sea otters spend a great deal of time at the surface feeding and grooming. While at the surface, the potential noise exposure of sea otters would be much reduced by the pressure release effect at the surface.

(f) 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 in the case of exposure to sounds from seismic surveys. Current NMFS policy regarding exposure of marine mammals to high-level sounds is that cetaceans and pinnipeds should not be exposed to impulsive sounds exceeding 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. 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.
- temporary threshold shift (TTS) is not injury and does not constitute "Level A harassment" in 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.

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 cause hearing impairment. In addition, many cetaceans show some avoidance of the area with ongoing seismic operations (see above). In these cases, the avoidance responses of the animals themselves will reduce or 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.

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. However, it is a temporary phenomenon, and (especially when mild) is not considered to represent physical damage or "injury". Rather, the onset of TTS is an indicator that, if the animals 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, among other considerations (Richardson et al. 1995). For sound exposures at or somewhat above the TTS threshold, hearing sensitivity recovers rapidly after exposure to the noise ends. Only a 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.

Toothed Whales.—Ridgway et al. (1997) and Schlundt et al. (2000) exposed bottlenose dolphins and beluga whales to single 1-s pulses of underwater sound. TTS generally became evident at received levels of 192 to 201 dB re 1 μPa rms at 3, 10, 20, and 75 kHz, with no strong relationship between frequency and onset of TTS across this range of frequencies. At 75 kHz, one dolphin exhibited TTS at 182 dB, and at 0.4 kHz, no dolphin or beluga exhibited TTS after exposure to levels up to 193 dB (Schlundt et al. 2000). There was no evidence of permanent hearing loss; all hearing thresholds returned to baseline values at the end of the study.

Finneran et al. (2000) exposed bottlenose dolphins and a beluga whale to single underwater pulses designed to generate sounds with pressure waveforms similar to those produced by distant underwater explosions. Pulses were of 5.1 to 13 ms in duration, and the measured frequency spectra showed a lack of energy below 1 kHz. Exposure to those impulses at peak received SPLs (sound pressure levels) of up to 221 dB re 1 μPa did not produce temporary threshold shift, although disruption of the animals' trained behaviors occurred.

A similar study was conducted by Finneran et al. (2002) using an 80 in^3 water gun, which generated impulses with higher peak pressures and total energy fluxes than used in the aforementioned study. Water gun impulses were expected to contain proportionally more energy at higher frequencies than airgun pulses (Hutchinson and Detrick 1984). "Masked TTS" (MTTS refers to the fact that measurements were obtained under conditions with substantial, but controlled, background noise) was observed in a beluga after exposure to a single impulse with peak-to-peak pressure of 226 dB re 1 μPa, peak pressure of 160 kPa, and total energy flux of 186 dB re 1 $\mu Pa^2 \cdot s$. Thresholds returned to within 2 dB of pre-exposure value ~4 min after exposure. No MTTS was observed in a bottlenose dolphin exposed to one pulse with peak-to-peak pressure of 228 dB re 1 μPa, equivalent to peak pressure 207 kPa and total energy flux of 188 dB re 1 $\mu Pa^2 \cdot s$ (Finneran et al. 2002). In this study, TTS was defined as occurring when there was a 6 dB or larger increase in post-exposure thresholds. Pulse duration at the highest exposure levels, where MTTS became evident in the beluga, was typically 10–13 ms.

The data quoted above all concern exposure of small odontocetes to single pulses of duration 1 s or shorter, generally at frequencies higher than the predominant frequencies in airgun pulses. With single short pulses, the TTS threshold appears to be (to a first approximation) a function of the energy content of the pulse (Finneran et al. 2002). The degree to which this generalization holds for other types of signals is unclear (Nachtigall et al. 2003).

Finneran et al. (2005) examined the effects of tone duration on TTS in bottlenose dolphins. Bottlenose dolphins were exposed to 3 kHz tones 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 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 white whales exposed to mid-frequency tones of durations 1-8 s, i.e., TTS onset occurs at a near-constant SEL, independent of exposure duration. That implies that a doubling of exposure time results in a 3 dB lower TTS threshold.

Mooney et al. (2005) exposed a bottlenose dolphin to octave-band noise ranging from 4 to 8 kHz at SPLs of 160 to 172 dB re 1 μPa for periods of 1.8 to 30 min. Recovery time depended on the shift and frequency, but full recovery always occurred within 40 min (Mooney et al. 2005). They reported that to induce TTS in a bottlenose dolphin, there is an inverse relationship of exposure time and SPL; as a first approximation, as exposure time was halved, an increase in noise SPL of 3 dB was required to induce the same amount of TTS.

Additional data are needed in order 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. Given the results of the aforementioned studies and a seismic pulse duration (as received at close range) of ~20 ms, the received level of a single seismic pulse might need to be on the order of 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 100 m around a seismic vessel.

To better characterize this radius, it would be necessary to determine the total energy that a mammal would receive as an airgun array approached, passed at various CPA distances, and moved away. At the present state of knowledge, it would also be necessary to assume that the effect is directly related to total 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, is a data gap

***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. However, in practice during seismic surveys, 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. (See above for evidence concerning avoidance responses by baleen whales.) This assumes that the ramp up (soft start) procedure is used when commencing airgun operations, to give whales near the vessel the opportunity to move away before they are exposed to sound levels that might be strong enough to elicit TTS. As discussed above, single-airgun experiments with bowhead, gray, and humpback whales show that those species do tend to move away when a single airgun starts firing nearby, which simulates the onset of a ramp up.

Pinnipeds.—TTS thresholds for pinnipeds exposed to brief pulses (either 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 (rms) of ~178 and 183 dB re 1 µPa and total energy fluxes of 161 and 163 dB re 1 $\mu Pa^2 \cdot s$ (Finneran et al. 2003). However, 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. For sounds of relatively long duration (20–22 min), Kastak et al. (1999) reported that they could induce mild TTS in California sea lions, harbor seals, and northern elephant seals by exposing them to underwater octave-band noise at frequencies in the 100–2000 Hz range. Mild TTS became evident when the received levels were 60–75 dB above the respective hearing thresholds, i.e., at received levels of about 135–150 dB. Three of the five subjects showed shifts of ~4.6–4.9 dB and all recovered to baseline hearing sensitivity within 24 hours of exposure.

Schusterman et al. (2000) showed that TTS thresholds of these pinnipeds were somewhat lower when the animals were exposed to the sound for 40 min than for 20–22 min, confirming that there is a duration effect in pinnipeds. Similarly, Kastak et al. (2005) reported that threshold shift magnitude increased with increasing SEL in a California sea lion and harbor seal. They noted that doubling the exposure duration from 25 to 50 min i.e., +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 h (Kastak et al. 2005). Kastak et al. (2005) suggested that sound exposure levels resulting in TTS onset in pinnipeds may range from 183 to 206 dB re 1 $\mu Pa^2 \cdot s$, depending on the absolute hearing sensitivity.

There are some indications that, for corresponding durations of sound, the harbor seal may incur TTS at somewhat lower received levels than do small odontocetes (Kastak et al. 1999, 2005; Ketten et al. 2001; *cf*. Au et al. 2000). However, TTS onset in the California sea lion and northern elephant seal may occur at a similar sound exposure level as in odontocetes (Kastak et al. 2005).

Likelihood of Incurring TTS.—A marine mammal within a radius of ≤100 m around a typical 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.

As shown above, most cetaceans show some degree of avoidance of seismic vessels operating an airgun array. 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 or above the surface and thus not exposed to strong sound pulses given the pressure-release effect 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.

Some pinnipeds show avoidance reactions to airguns, but their avoidance reactions are not as strong or consistent as those of cetaceans (see above). Pinnipeds occasionally seem to be attracted to operating seismic vessels. As previously noted, there are no specific data on TTS thresholds of pinnipeds exposed to single or multiple low-frequency pulses. It is not known whether pinnipeds near operating seismic vessels, and especially those individuals that linger nearby, would incur significant TTS.

NMFS (1995, 2000) concluded that cetaceans should not be exposed to pulsed underwater noise at received levels exceeding 180 dB re 1 µPa (rms). The corresponding limit for pinnipeds has been set at 190 dB, although the HESS Team (1999) recommended a 180-dB limit for pinnipeds in California. The 180 and 190 dB (rms) levels 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 any TTS measurements for marine mammals were available, one could not be certain that there would be no injurious effects, auditory or otherwise, to marine mammals. As discussed above, TTS data that have subsequently become available imply that, at least for dolphins, TTS is unlikely to occur unless the dolphins are exposed to airgun pulses stronger than 180 dB re 1 µPa rms. Furthermore, it should be noted that mild TTS is not injury, and in fact is a natural phenomenon experienced by marine and terrestrial mammals (including humans).

It has been shown that most large whales tend to avoid ships and associated seismic operations. In addition, ramping up airgun arrays, which is standard operational protocol for many seismic operators, should allow cetaceans to move away from the seismic source and to avoid being exposed to the full acoustic output of the airgun array. [Three species of baleen whales that have been exposed to pulses from single airguns showed avoidance (Malme et al. 1984–1988; Richardson et al. 1986; McCauley et al. 1998, 2000a,b). This strongly suggests that baleen whales will begin to move away during the initial stages of a ramp up, when a single airgun is fired.] Thus, whales will likely not be exposed to high levels of airgun sounds. Likewise, any whales close to the trackline could move away before the sounds from the approaching seismic vessel become sufficiently strong for there to be any potential for TTS or other hearing impairment. Therefore, there is little potential for whales to be close enough to an airgun array to experience TTS. Furthermore, in the event that a few individual cetaceans did incur TTS through exposure to airgun sounds, this is a temporary and reversible phenomenon.

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, while in other cases, the animal has an impaired ability to hear sounds in specific frequency ranges. Physical damage to a mammal's hearing apparatus can occur if it is exposed to sound impulses that have very high peak pressures, especially if they have very short rise times (time required for sound pulse to reach peak pressure from the baseline pressure). Such damage can result in a permanent decrease in functional sensitivity of the hearing system at some or all frequencies.

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 Finneran et al. 2002), there has been speculation about the possibility that some individuals occurring very close to airguns might incur TTS (Richardson et al. 1995, p. 372*ff*).

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. The low-to-moderate levels of TTS that have been induced in captive odontocetes and pinnipeds during recent 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; Nachtigall et al. 2003, 2004). However, very prolonged exposure to sound strong enough to elicit TTS, or shorter-term exposure to sound levels well above the TTS threshold, can cause PTS, at least in terrestrial mammals (Kryter 1985). In terrestrial mammals, the received sound level from a single non-impulsive sound exposure must be far above the TTS threshold for any risk of permanent hearing damage (Kryter 1994; Richardson et al. 1995). However, there is special concern about strong sounds whose pulses have very rapid rise times. In terrestrial mammals, there are situations when pulses with rapid rise times can result in PTS even though their levels are only a few dB higher than the level causing slight TTS. The rise time of airgun pulses is fast, but not nearly as fast as that of explosions, which are the main concern in this regard.

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

- exposure to single very intense sound,
- 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) has 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.

Sound impulse duration, peak amplitude, rise time, and number of pulses are the main factors thought to determine the onset and extent of PTS. Based on existing data, 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.

Given that marine mammals are unlikely to be exposed to received levels of seismic pulses that could cause TTS, it is highly unlikely that they would sustain permanent hearing impairment. If we assume that the TTS threshold for exposure to a series of seismic pulses may be on the order of 220 dB re 1 μPa (pk-pk) in odontocetes, then the PTS threshold might be as high as 240 dB re 1 μPa (pk-pk) or 10 bar-m. Such levels are found only in the immediate vicinity of the largest airguns (Richardson et al. 1995:137; Caldwell and Dragoset 2000). It is very unlikely that an odontocete would remain within a few meters of a large airgun for sufficiently long to incur PTS. The TTS (and thus PTS) thresholds of baleen whales and/or pinnipeds (e.g., harbor seal) may be lower, and thus may extend to a somewhat greater distance. However, 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. Pinnipeds, on the other hand, often do not show strong avoidance of operating airguns.

Although it is unlikely that airgun operations during most seismic surveys would cause PTS in marine mammals, caution is warranted given the limited knowledge about noise-induced hearing damage in marine mammals, particularly baleen whales. Commonly-applied monitoring and mitigation measures, including visual monitoring, course alteration, ramp ups, and power downs or shut downs of the airguns when mammals are seen within the "safety radii", would minimize the already-low probability of exposure of marine mammals to sounds strong enough to induce PTS.

(g) 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. However, the spatiotemporal association of mass strandings of beaked whales with naval exercises and an L-DEO seismic survey in 2002 has raised the possibility that beaked whales may be especially susceptible to injury and/or behavioral reactions that can lead to stranding when exposed to strong pulsed sounds.

In March 2000, several beaked whales that had been exposed to repeated pulses from high intensity, mid-frequency military sonars stranded and died in the Providence Channels of the Bahamas Islands, and were subsequently found to have incurred cranial and ear damage (NOAA and USN 2001). Based on post-mortem analyses, it was concluded that an acoustic event caused hemorrhages in and near the auditory region of some beaked whales. These hemorrhages occurred before death. They would not necessarily have caused death or permanent hearing damage, but could have compromised hearing and navigational ability (NOAA and USN 2001). The researchers concluded that acoustic exposure caused this damage and triggered stranding, which resulted in overheating, cardiovascular collapse, and physiological shock that ultimately led to the death of the stranded beaked whales. During the event, five naval vessels used their AN/SQS-53C or -56 hull-mounted active sonars for a period of 16 h. The sonars produced narrow (<100 Hz) bandwidth signals at center frequencies of 2.6 and 3.3 kHz (-53C), and 6.8 to 8.2 kHz (-56). The respective source levels were usually 235 and 223 dB re 1 μPa, but the -53C briefly operated at an unstated but substantially higher source level. The unusual bathymetry and constricted channel where the strandings occurred were conducive to channeling sound. This, and the extended operations by multiple sonars, apparently prevented escape of the animals to the open sea. In addition to the strandings, there are reports that beaked whales were no longer present in the Providence Channel region after the event, suggesting that other beaked whales either abandoned the area or perhaps died at sea (Balcomb and Claridge 2001).

Other strandings of beaked whales associated with operation of military sonars have also been reported (e.g., Simmonds and Lopez-Jurado 1991; Frantzis 1998). In these cases, it was not determined whether there were noise-induced injuries to the ears or other organs. Another stranding of beaked whales (15 whales) happened on 24–25 September 2002 in the Canary Islands, where naval maneuvers were taking place. Based on the strandings in the Canary Islands, Jepson et al. (2003) proposed that cetaceans might be subject to decompression injury in some situations. Fernández et al. (2005a) showed that those beaked whales did indeed have gas bubble-associated lesions and 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). These effects were suspected to be induced by exposure to sonar sounds, but the mechanism of injury was not auditory. Most of the afflicted species were deep divers. 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; Moore and Early 2004; Arbelo et al. 2005; Fernández et al. 2005a; Jepson et al. 2005b). Previously it was widely assumed that diving marine mammals are not subject to the bends or air embolism.

It is important to note that seismic pulses and mid-frequency sonar pulses are quite different. Sounds produced by the types of airgun arrays used to profile sub-sea geological structures 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 (though the center frequency may change over time). Because seismic and sonar sounds have considerably different characteristics and duty cycles, 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 directly or indirectly to mortality suggests that caution is warranted when dealing with exposure of marine mammals to any high-intensity pulsed sound.

As noted earlier, in Sept. 2002, there was a stranding of two Cuvier's beaked whales in the Gulf of California (Mexico) when a seismic survey by the R/V *Maurice Ewing* was underway in the general area. (Malakoff 2002). The airgun array in use during that project was the *Ewing*'s 20-airgun 8490-in^3 array. This might be a first indication that seismic surveys can have effects, at least on beaked whales, similar to the suspected effects of naval sonars. However, the evidence linking the Gulf of California strandings to the seismic surveys was inconclusive, and not based on any physical evidence (Hogarth 2002; Yoder 2002). The ship was also operating its multibeam bathymetric sonar at the same time but, as discussed elsewhere, this sonar had much less potential than the aforementioned naval sonars to affect beaked whales. Although the link between the Gulf of California strandings and the seismic (plus multi-beam sonar) survey is inconclusive, this plus the various incidents involving beaked whale strandings "associated with" naval exercises suggests a need for caution in conducting seismic surveys in areas occupied by beaked whales.

(h) Non-auditory Physiological Effects

Possible types of non-auditory physiological effects or injuries that might theoretically occur in marine mammals exposed to strong underwater sound might include stress, neurological effects, bubble formation, and other types of organ or tissue damage. However, studies examining such effects are limited. If any such effects do occur, they would probably be limited to unusual situations. Those could include cases when animals are exposed at close range for unusually long periods, or when the sound is strongly channeled with less-than-normal propagation loss, or when dispersal of the animals is constrained by shorelines, shallows, etc.

Long-term exposure to anthropogenic noise may have the potential of causing physiological stress that could affect the health of individual animals or their reproductive potential, which in turn could (theoretically) cause effects at the population level (Gisiner [ed.] 1999). Romano et al. (2004) examined the effects of single underwater impulse sounds from a seismic water gun (up to 228 dB re 1 μPa peak-to peak pressure) and single pure tones (sound pressure level up to 201 dB re 1 μPa) on the nervous and immune systems of a beluga and a bottlenose dolphin. They found that neural-immune changes to noise exposure were minimal. Although levels of some stress-released substances (e.g., catecholamines) changed significantly with exposure to sound, levels returned to baseline after 24 hr. Further information about the occurrence of noise-induced stress in marine mammals is not available at this time. However, it is doubtful that any single marine mammal would be exposed to strong seismic sounds for sufficiently long that significant physiological stress would develop. This is particularly so in the case of seismic surveys where the tracklines are long and/or not closely spaced.

High sound levels could potentially cause bubble formation of diving mammals that in turn could cause an air or fat embolism, tissue separation, and high, localized pressure in nervous tissue (Gisiner [ed.] 1999; Houser et al. 2001). Moore and Early (2004) suggested that sperm whales are subjected to natural bone damage caused by repeated decompression events during their lifetimes. Those authors hypothesized that sperm whales are neither anatomically nor physiologically immune to the effects of deep diving. The possibility that marine mammals may be subject to decompression sickness 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 air cavity resonance or bubble formation in tissues caused by exposure to noise from naval sonar. A panel of experts concluded that resonance in air-filled structures was not likely to have caused this stranding. Among other reasons, the air spaces in marine mammals are too large to be susceptible to resonant frequencies emitted by mid- or low-frequency sonar; lung tissue damage has not been observed in any mass, multi-species stranding of beaked whales; and the duration of sonar pings is likely too short to induce vibrations that could damage tissues (Gentry [ed.] 2002). Opinions were less conclusive about the possible role of gas (nitrogen) bubble formation/growth in the Bahamas stranding of beaked whales. Workshop participants did not rule out the possibility that bubble formation/growth played a role in the stranding and participants acknowledged that more research is needed in this area.

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 14 beaked whales that stranded in the Canary Islands close to the site of an international naval exercise in September 2002. The interpretation that the effect was related to decompression injury was initially unproven (Piantadosi and Thalmann 2004; Fernández et al. 2004). However, there is increasing evidence and suspicion that decompression illness can occur in beaked whales and perhaps some other odontocetes, and that there may, at times, be a connection to noise exposure (see preceeding section).

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; Moore and Early 2004; Arbelo et al. 2005; Fernández et al. 2005a; Jepson et al. 2005b). Thus, air and fat embolisms could be a mechanism by which exposure to strong sounds could, indirectly, result in non-auditory injuries and perhaps death. However, even if those effects can occur during exposure to mid-frequency sonar, there is no evidence that those types of effects could occur in response to airgun sounds.

The only available information on acoustically-mediated bubble growth in marine mammals is modeling assuming prolonged exposure to sound. Crum et al. (2005) tested *ex vivo* bovine liver, kidney, and blood to determine the potential role of short pulses of sound to induce bubble nucleation or decompression sickness. In their experiments, supersaturated bovine tissues and blood showed extensive bubble production when exposed to low-frequency sound. Exposure to 37 kHz at ~50 kPa caused bubble formation in blood and liver tissue, and exposure to three acoustic pulses of 10,000 cycles, each 1 min, also produced bubbles in kidney tissue. Crum et al. (2005) speculated that marine mammal tissue may be affected in similar ways under such conditions. However, these results may not be directly applicable to free-ranging marine mammals exposed to sonar.

In summary, very little is known about the potential for seismic survey sounds to cause either auditory impairment or other non-auditory physical effects in marine mammals. Available data suggest that such effects, if they occur at all, would be limited to short distances. However, the available data do not allow for meaningful quantitative predictions of the numbers (if any) of marine mammals that might be affected in these ways. Marine mammals that show behavioral avoidance of seismic vessels, including most baleen whales, some odontocetes, and some pinnipeds, are unlikely to incur auditory impairment or other physical effects.

Literature Cited

Akamatsu, T., Y. Hatakeyama and N. Takatsu. 1993. Effects of pulsed sounds on escape behavior of false killer whales. **Nippon Suisan Gakkaishi** 59(8):1297-1303.

Anonymous. 1975. Phantom killer whales. **S. Afr. Ship. News Fish. Ind. Rev.** 30(7):50-53.

Arbelo, M., M. Méndez, E. Sierra, P. Castro, J. Jaber, P. Calabuig, M. Carrillo and A. Fernández. 2005. Novel "gas embolic syndrome" in beaked whales resembling decompression sickness. Abstr. 16th Bien. Conf. Biol. Mar. Mamm., San Diego, CA, 12-16 Dec. 2005.

Arnold, B.W. 1996. Visual monitoring of marine mammal activity during the Exxon 3-D seismic survey: Santa Ynez unit, offshore California 9 November to 12 December 1995. Rep. by Impact Sciences Inc., San Diego, CA, for Exxon Company, U.S.A., Thousand Oaks, CA. 20 p.

Au, W.W.L. 1993. The sonar of dolphins. Springer-Verlag, New York, NY. 277 p.

Au, W. W. L., A.N. Popper and R.R. Fay. 2000. Hearing by Whales and Dolphins. Springer-Verlag, New York, NY. 458 p.

Au, W., J. Darling and K. Andrews. 2001. High-frequency harmonics and source level of humpback whale songs. **J. Acoust. Soc. Am.** 110(5, Pt. 2):2770.

Balcomb, K.C., III and D.E. Claridge. 2001. A mass stranding of cetaceans caused by naval sonar in the Bahamas. **Bahamas J. Sci.** 8(2):2-12.

Bowles, A.E., M. Smultea, B. Würsig, D.P. DeMaster and D. Palka. 1994. Relative abundance and behavior of marine mammals exposed to transmissions from the Heard Island Feasibility Test. **J. Acoust. Soc. Am.** 96:2469-2484.

Bullock, T.H., T.J. O'Shea and M.C. McClune. 1982. Auditory evoked potentials in the West Indian manatee (Sirenia: *Trichechus manatus*). **J. Comp. Physiol. A** 148(4):547-554.

Burgess, W.C. and C.R. Greene, Jr. 1999. Physical acoustics measurements. p. 3-1 to 3-63 *In*: W.J. Richardson (ed.), Marine mammal and acoustical monitoring of Western Geophysical's open-water seismic program in the Alaskan Beaufort Sea, 1998. LGL Rep. TA22303. Rep. from LGL Ltd., King City, Ont., and Greene-ridge Sciences Inc., Santa Barbara, CA, for Western Geophysical, Houston, TX, and U.S. Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 390 p.

Calambokidis, J. and S.D. Osmek. 1998. Marine mammal research and mitigation in conjunction with air gun operation for the USGS `SHIPS' seismic surveys in 1998. Draft Rep. from Cascadia Research, Olympia, WA, for U.S. Geol. Surv., Nat. Mar. Fish. Serv., and Minerals Manage. Serv.

Caldwell, J. 2002. Does air-gun noise harm marine mammals? **The Leading Edge** 2002(1, Jan.):75-78.

Caldwell, J. and W. Dragoset. 2000. A brief overview of seismic air-gun arrays. **The Leading Edge** 2000(8, Aug.): 898-902.

Cavanagh, R.C. 2000. Criteria and thresholds for adverse effects of underwater noise on marine animals. Rep by Science Applications Intern. Corp., McLean, VA, for Air Force Res. Lab., Wright-Patterson AFB, Ohio. AFRL-HE-WP-TR-2000-0092.

Crum, L.A. M.R. Bailey, J. Guan, P.R. Hilmo, S.G. Kargl and T.J. Matula. 2005. Monitoring bubble growth in supersaturated blood and tissue ex vivo and the relevance to marine mammal bioeffects. **Acoust. Res. Let. Online** 6(3):214-220.

Dahlheim, M.E 1987. Bio-acoustics of the gray whale (*Eschrichtius robustus*). Ph.D. Thesis, Univ. Brit. Columbia, Vancouver, B.C. 315 p.

Duncan, P.M. 1985. Seismic sources in a marine environment. p. 56-88 *In*: Proc. Workshop on Effects of Explosives Use in the Marine Environment, Jan. 1985, Halifax, N.S. Tech. Rep. 5. Can. Oil & Gas Lands Admin. Environ. Prot. Br., Ottawa, Ont. 398 p.

Fernández, A., M. Arbelo, R. Deaville, I.A.P. Patterson, P. Castro, J.R. Baker, E. Degollada, H.M. Ross, P. Herráez, A.M. Pocknell, E. Rodríguez, F.E. Howie, A. Espinosa, R.J. Reid, J.R. Jaber, V. Martin, A.A. Cunningham and P.D. Jepson. 2004. Pathology: whales, sonar and decompression sickness (reply). **Nature** 428(6984).

Fernández, A., J.F. Edwards, F. Rodriquez, A.E. de los Monteros, P. Herráez, P. Castro, J.R. Jaber, V. Martin and M. Arbelo. 2005a. "Gas and fat embolic syndrome" involving a mass stranding of beaked whales (Family Ziphiidae) exposed to anthropogenic sonar signals. **Vet. Pathol.** 42(4):446-457.

Fernández, A., M. Méndez, E. Sierra, A. Godinho, P. Herráez, A.E. De los Monteros, F. Rodrigues and M. Arbelo. 2005b. New gas and fat embolic pathology in beaked whales stranded in the Canary Islands. Abstr. 16th Bien. Conf. Biol. Mar. Mamm., San Diego, CA, 12-16 Dec. 2005.

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

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

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

Finneran, J.J., R. Dear, D.A. Carder and S.H. Ridgway. 2003. Auditory and behavioral responses of California sea lions (*Zalophus californianus*) to single underwater impulses from an arc-gap transducer. **J. Acoust. Soc. Am.** 114(3):1667-1677.

Fish, J.F. and J.S. Vania. 1971. Killer whale, *Orcinus orca*, sounds repel white whales, *Delphinapterus leucas*. **Fish. Bull.** 69(3):531-535.

Fox, C.G., R.P. Dziak and H. Matsumoto. 2002. NOAA efforts in monitoring of low-frequency sound in the global ocean. **J. Acoust. Soc. Am.** 112(5, Pt. 2):2260.

Frantzis, A. 1998. Does acoustic testing strand whales? **Nature** 392(6671):29.

Frost, K.J., L.F. Lowry and R.R. Nelson. 1984. Belukha whale studies in Bristol Bay, Alaska. pp. 187-200 *In*: B.R. Melteff and D.H. Rosenberg (eds.), Proc. workshop on biological interactions among marine mammals and commercial fisheries in the southeastern Bering Sea, Oct. 1983, Anchorage, AK. Univ. Alaska Sea Grant Rep. 84-1. Univ. Alaska, Fairbanks, AK.

Gentry, R. (ed.). 2002. Report of the workshop on acoustic resonance as a source of tissue trauma in cetaceans, Silver Spring, MD, April 2002. Nat. Mar. Fish. Serv. 19 p. Available at http://www.nmfs.noaa.gov/prot_res/PR2/Acoustics_Program/acoustics.html

Gentry, R., A. Bowles, W. Ellison, J. Finneran, C. Greene, D. Kastak, D. Ketten, J. Miller, P. Nachtigall, W.J. Richardson, B. Southall, J. Thomas and P. Tyack. 2004. Noise exposure criteria. Presentation to U.S. Mar. Mamm. Commis. Advis. Commit. on Acoustic Impacts on Marine Mammals, Plenary Meeting 2, Arlington, VA, April 2004. Available at http://mmc.gov/sound/plenary2/pdf/gentryetal.pdf

Gerstein, E.R., L.A. Gerstein, S.E. Forsythe and J.E. Blue. 1999. The underwater audiogram of a West Indian manatee (*Trichechus manatus*). **J. Acoust. Soc. Am.** 105(6):3575-3583.

Gisiner, R.C. (ed.). 1999. Proceedings/Workshop on the effects of anthropogenic noise in the marine environment, Bethesda, MD, Feb. 1998. Office of Naval Research, Arlington, VA. 141 p. Available at www.onr.navy.mil/sci%5Ftech/personnel/cnb%5Fsci/proceed.pdf.

Goold, J.C. 1996a. Acoustic assessment of common dolphins off the west Wales coast, in conjunction with 16th round seismic surveying. Rep. from School of Ocean Sciences, Univ. Wales, Bangor, Wales, for Chevron UK Ltd, Repsol Explor. (UK) Ltd., and Aran Energy Explor. Ltd. 22 p.

Goold, J.C. 1996b. Acoustic assessment of populations of common dolphin *Delphinus delphis* in conjunction with seismic surveying. **J. Mar. Biol. Assoc. U.K.** 76:811-820.

Goold, J.C. 1996c. Acoustic cetacean monitoring off the west Wales coast. Rep. from School of Ocean Sciences, Univ. Wales, Bangor, Wales, for Chevron UK Ltd, Repsol Explor. (UK) Ltd, and Aran Energy Explor. Ltd. 20 p.

Goold, J.C. and P.J. Fish. 1998. Broadband spectra of seismic survey air-gun emissions, with reference to dolphin auditory thresholds. **J. Acoust. Soc. Am.** 103(4):2177-2184.

Gordon, J., D. Gillespie, J. Potter, A. Frantzis, M.P. Simmonds, R. Swift and D. Thompson. 2004. A review of the effects of seismic surveys on marine mammals. **Mar. Technol. Soc. J.** 37(4):16-34. Also available at http://www.pelagosinstitute.gr/en/pelagos/pdfs/Gordon%20et%20al.%202004,%20Review%20of%20Seismic%20Surveys%20Effects.pdf

Greene, C.R. 1997. An autonomous acoustic recorder for shallow arctic waters**. J. Acoust. Soc. Am.** 102(5, Pt. 2):3197.

Greene, C.R., Jr. and W.J. Richardson. 1988. Characteristics of marine seismic survey sounds in the Beaufort Sea. **J. Acoust. Soc. Am.** 83(6):2246-2254.

Greene, G.D., F.R. Engelhardt and R.J. Paterson (eds.). 1985. Proceedings of the workshop on effects of explosives use in the marine environment. Canadian Oil and Gas Lands Admin. and Environ. Prot. Branch, Ottawa, Ont. 398 p.

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

Harris, R.E., G.W. Miller and W.J. Richardson. 2001. Seal responses to airgun sounds during summer seismic surveys in the Alaskan Beaufort Sea. **Mar. Mamm. Sci.** 17(4):795-812.

HESS. 1999. High Energy Seismic Survey review process and interim operational guidelines for marine surveys offshore Southern California. Report from High Energy Seismic Survey Team for California State Lands Commission and U.S. Minerals Management Service [Camarillo, CA]. 39 p. + App. Available at www.mms.gov/omm/pacific/lease/fullhessrept.pdf

Holst, M., M.A. Smultea, W.R. Koski and B. Haley. 2005a. Marine mammal and sea turtle monitoring during Lamont-Doherty Earth Observatory's marine seismic program off the Northern Yucatán Peninsula in the Southern Gulf of Mexico, January–February 2005. LGL Rep. TA2822-31. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 96 p.

Holst, M., M.A. Smultea, W.R. Koski and B. Haley. 2005b. Marine mammal and sea turtle monitoring during Lamont-Doherty Earth Observatory's marine seismic program in the Eastern Tropical Pacific Ocean off Central America, November–December 2004. LGL Rep. TA2822-30. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 125 p.

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

Hooker, S.K., R.W. Baird, S. Al-Omari, S. Gowans and H. Whitehead. 2001. Behavioural reactions of northern bottlenose whales (*Hyperoodon ampullatus*) to biopsy darting and tag attachment procedures. **Fish. Bull.** 99(2):303-308.

Houser, D.S., R. Howard and S. Ridgway. 2001. Can diving-induced tissue nitrogen supersaturation increase the chance of acoustically driven bubble growth in marine mammals? **J. Theor. Biol.** 213(2):183-195.

Hutchinson, D.R. and R.S. Detrick. 1984. Water gun vs. air gun: a comparison. **Mar. Geophys. Res.** 6(3):295-310.

Jefferson, T.A. and B.E. Curry. 1994. Review and evaluation of potential acoustic methods of reducing or eliminating marine mammal-fishery interactions. Rep. from Mar. Mamm. Res. Prog., Texas A & M Univ., College Station, TX, for U.S. Mar. Mamm. Comm., Washington, DC. 59 p. NTIS PB95-100384.

Jepson, P.D., M. Arbelo, R. Deaville, I.A.P. Patterson, P. Castro, J.R. Baker, E. Degollada, H.M. Ross, P. Herráez, A.M. Pocknell, F. Rodríguez, F.E. Howie, A. Espinosa, R.J. Reid, J.R. Jaber, V. Martin, A.A. Cunningham and A. Fernández. 2003. Gas-bubble lesions in stranded cetaceans. **Nature** 425(6958):575-576.

Jepson, P.D., D.S. Houser, L.A. Crum, P.L. Tyack and A. Fernández. 2005a. Beaked whales, sonar and the "bubble hypothesis". Abstr. 16th Bien. Conf. Biol. Mar. Mamm., San Diego, CA, 12-16 Dec. 2005.

Jepson, P.D. R. Deaville, I.A.P. Patterson, A.M. Pocknell, H.M. Ross, J.R. Baker, F.E. Howie, R.J. Reid, A. Colloff and A.A. Cunningham. 2005b. Acute and chronic gas bubble lesions in cetaceans stranded in the United Kingdom. **Vet. Pahol.** 42(3):291-305.

Jochens, A.E. and D.C. Biggs (eds.). 2003. Sperm whale seismic study in the Gulf of Mexico; Annual Report: Year 1. U.S. Dept. of the Int., Min. Manage. Serv., Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2003-069. 139 p.

Johnson, S.R. 2002. Marine mammal mitigation and monitoring program for the 2001 Odoptu 3-D seismic survey, Sakhalin Island Russia: Executive summary. Rep. from LGL Ltd, Sidney, B.C., for Exxon Neftegas Ltd., Yuzhno-Sakhalinsk, Russia. 49 p. Also available as Working Paper SC/02/WGW/19, Int. Whal. Comm., Western Gray Whale Working Group Meeting, Ulsan, South Korea, 22-25 October 2002. 48 p.

Kastak, D. and R.J. Schusterman. 1998. Low-frequency amphibious hearing in pinnipeds: methods, measurements, noise and ecology. **J. Acoust. Soc. Am.** 103(4): 2216-2228.

Kastak, D. and R.J. Schusterman. 1999. In-air and underwater hearing sensitivity of a northern elephant seal (*Mirounga angustirostris*). **Can. J. Zool.** 77(11):1751-1758.

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

Kastak, D., B. Southall, M. Holt, C. Reichmuth Kastak and R. Schusterman. 2004. Noise-induced temporary threshold shifts in pinnipeds: effects of noise energy. **J. Acoust. Soc. Am.** 116(4, Pt. 2):2531-2532, plus oral presentation at 148th Meeting, Acoust. Soc. Am., San Diego, CA, Nov. 2004.

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

Kastelein, R.A., P. Mosterd, B. van Santen, M. Hagedoorn and D. de Haan. 2002. Underwater audiogram of a Pacific walrus (*Odobenus rosmarus divergens*) measured with narrow-band frequency-modulated signals. **J. Acoust. Soc. Am.** 112(5):2173-2182.

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

Ketten, D.R. 1991. The marine mammal ear: specializations for aquatic audition and echolocation. p. 717-750 *In*: D. Webster, R. Fay and A. Popper (eds.), The Biology of Hearing. Springer-Verlag, Berlin.

Ketten, D.R. 1992. The cetacean ear: form, frequency, and evolution. p. 53-75 *In*: J. A. Thomas, R. A. Kastelein and A. Ya Supin (eds.), Marine Mammal Sensory Systems. Plenum, New York. 773 p.

Ketten, D.R. 1994. Functional analysis of whale ears: adaptations for underwater hearing. **IEEE Proc. Underwat. Acoust.** 1:264-270.

Ketten, D.R. 1995. Estimates of blast injury and acoustic trauma zones for marine mammals from underwater explosions. p. 391-407 *In:* R.A. Kastelein, J.A. Thomas, and P.E. Nachtigall (eds.), Sensory systems of aquatic mammals. De Spil Publ., Woerden, Netherlands. 588 p.

Ketten, D.R. 2000. Cetacean ears. p. 43-108 *In*: W.W.L. Au, A.N. Popper and R.R. Fay (eds.), Hearing by Whales and Dolphins. Springer-Verlag, New York, NY. 485 p.

Ketten, D.R., J. Lien and S. Todd. 1993. Blast injury in humpback whale ears: evidence and implications. **J. Acoust. Soc. Am.** 94(3, Pt. 2):1849-1850.

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

Klima, E.F., G.R. Gitschlag and M.L. Renaud. 1988. Impacts of the explosive removal of offshore petroleum platforms on sea turtles and dolphins. **Mar. Fish. Rev.** 50(3):33-42.

Kryter, K.D. 1985. The effects of noise on man, 2nd ed. Academic Press, Orlando, FL. 688 p.

Kryter, K.D. 1994. The handbook of hearing and the effects of noise. Academic Press, Orlando, FL. 673 p.

Lesage, V., C. Barrette, M.C.S. Kingsley and B. Sjare. 1999. The effect of vessel noise on the vocal behavior of belugas in the St. Lawrence River estuary, Canada. **Mar. Mamm. Sci.** 15(1):65-84.

Ljungblad, D.K., B. Würsig, S.L. Swartz and J.M. Keene. 1988. Observations on the behavioral responses of bowhead whales (*Balaena mysticetus*) to active geophysical vessels in the Alaskan Beaufort Sea. **Arctic** 41(3):183-194.

Madsen, P.T., B. Mohl, B.K. Nielsen and M. Wahlberg. 2002. Male sperm whale behavior during exposures to distant seismic survey pulses. **Aquat. Mamm.** 28(3):231-240.

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

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

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

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

Malme, C.I., B. Würsig, J.E. Bird and P. Tyack. 1986. Behavioral responses of gray whales to industrial noise: feeding observations and predictive modeling. Outer Cont. Shelf Environ. Assess. Progr., Final Rep. Princ. Invest., NOAA, Anchorage, AK 56(1988):393-600. BBN Rep. 6265. 600 p. OCS Study MMS 88-0048; NTIS PB88-249008.

Malme, C.I., B. Würsig, B., J.E. Bird and P. Tyack. 1987. Observations of feeding gray whale responses to controlled industrial noise exposure. p 55-73 *In:* W.M. Sackinger, M.O. Jeffries, J.L. Imm and S.D. Treacy (eds.), Port and Ocean Engineering Under Arctic Conditions. Vol. II. Symposium on noise and marine mammals. Published 1988. University of Alaska Fairbanks, Fairbanks AK.

Malme, C.I., B. Würsig, J.E. Bird and P. Tyack. 1988. Observations of feeding gray whale responses to controlled industrial noise exposure. p. 55-73 *In*: W.M. Sackinger, M.O. Jeffries, J.L. Imm and S.D. Treacy (eds.), Port and ocean engineering under arctic conditions, vol. II. Geophysical Inst., Univ. Alaska, Fairbanks, AK. 111 p.

Mann, D.A., R.A. Varela, J.D. Goldstein, S.D. McCulloch, G.D. Bossart, J.J. Finneran, D. Houser and M.L.H. Cook. 2005. Gervais' beaked whale auditory evoked potential hearing measurements. Abstr. 16th Bien. Conf. Biol. Mar. Mamm., San Diego, CA, 12-16 Dec. 2005.

Mate, B. 2003. Seasonal distribution and habitat characterization of sperm whales in the Gulf of Mexico from Argos satellite-monitored radio tracking. Abstr. 15th Bien. Conf. Biol. Mar. Mamm., Greensboro, NC, 14-19 Dec. 2003.

Mate, B.R. and J.T. Harvey. 1987. Acoustical deterrents in marine mammal conflicts with fisheries. ORESU-W-86-001. Oregon State Univ., Sea Grant Coll. Progr., Corvallis, OR. 116 p.

Mate, B.R., K.M. Stafford and D.K. Ljungblad. 1994. A change in sperm whale (*Physeter macrocephalus*) distribution correlated to seismic surveys in the Gulf of Mexico. **J. Acoust. Soc. Am.** 96(2):3268-3269.

McCall Howard, M.P. 1999. Sperm whales *Physeter macrocephalus* in the Gully, Nova Scotia: Population, distribution, and response to seismic surveying. B.Sc. (Honors) Thesis. Dalhousie Univ., Halifax, N.S.

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

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

McCauley, R.D., J. Fewtrell, A.J. Duncan, M.-N. Jenner, M-N., C. Jenner, R.I.T. Prince, A. Adhitya, K. McCabe and J. Murdoch. 2000b. Marine seismic surveys - a study of environmental implications. **APPEA J.** 40:692-708.

McDonald, M.A., J.A. Hildebrand and S.C. Webb. 1995. Blue and fin whales observed on a seafloor array in the Northeast Pacific. **J. Acoust. Soc. Am.** 98(2 Pt.1):712-721.

Méndez, M., M. Arbelo, E. Sierra, A. Godinho, M.J. Caballero, J. Jaber, P. Herráez and A. Fernández. 2005. Lung fat embolism in cetaceans stranded in Canary Islands. Abstr. 16th Bien. Conf. Biol. Mar. Mamm., San Diego, CA, 12-16 Dec. 2005.

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

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

Mooney, T.A., P.E. Nachtigall, W.W.L. Au, M. Breese and S. Vlachos. 2005. Bottlenose dolphins: effects of noise duration, intensity, and frequency. Abstr. 16th Bien. Conf. Biol. Mar. Mamm., San Diego, CA, 12-16 Dec. 2005.

Moore, M.J. and G.A. Early. 2004. Cumulative sperm whale bone damage and the bends. **Science** 306:2215.

Moulton, V.D. and J.W. Lawson. 2002. Seals, 2001. p. 3-1 to 3-48 *In*: W.J. Richardson (ed.), Marine mammal and acoustical monitoring of WesternGeco's open water seismic program in the Alaskan Beaufort Sea, 2001. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for WesternGeco, Houston, TX, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. LGL Rep. TA2564-4.

Moulton, V.D. and G.W. Miller. In press. Marine mammal monitoring of a seismic survey on the Scotian Slope, 2003. **Can. Tech. Rep Fish. Aquat. Sci.** 2003.

Nachtigall, P.E., J.L. Pawloski and W.W.L. Au. 2003. Temporary threshold shifts and recovery following noise exposure in the Atlantic bottlenosed dolphin (*Tursiops truncatus*). **J. Acoust. Soc. Am.** 113(6):3425-3429.

Nachtigall, P.E., A.Y. Supin, J. Pawloski and W.W.L. Au. 2004. Temporary threshold shifts after noise exposure in the bottlenose dolphin (*Tursiops truncatus*) measured using evoked auditory potentials. **Mar. Mamm. Sci.** 20 (4):673-687

Nieukirk, S.L., K.M. Stafford, D.K. Mellinger, R.P. Dziak and C.G. Fox. 2004. Low-frequency whale and seismic airgun sounds recorded in the mid-Atlantic Ocean. **J. Acoust. Soc. Am.** 115(4):1832-1843.

Nieukirk, S.L., D.K. Mellinger, J.A. Hildebrand, M.A. McDonald and R.P. Dziak. 2005. Downward shift in the frequency of blue whale vocalizations. Abstr. 16th Bien. Conf. Biol. Mar. Mamm., San Diego, CA, 12-16 Dec. 2005.

NMFS. 1995. Small takes of marine mammals incidental to specified activities; offshore seismic activities in southern California. **Fed. Regist.** 60(200, 17 Oct.):53753-53760.

NMFS. 2000. Small takes of marine mammals incidental to specified activities; marine seismic-reflection data collection in southern California/Notice of receipt of application. **Fed. Regist.** 65(60, 28 Mar.):16374-16379.

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

NOAA and USN. 2001. Joint interim report: Bahamas marine mammal stranding event of 14-16 March 2000. U.S. Dep. Commer., Nat. Oceanic Atmos. Admin., Nat. Mar. Fish. Serv., Sec. Navy, Assis. Sec. Navy, Installations and Envir. 61 p.

Parks, S.E., C.W. Clark and P.L. Tyack. 2005. North Atlantic right whales shift their frequency of calling in response to vessel noise. Abstr. 16th Bien. Conf. Biol. Mar. Mamm., San Diego, CA, 12-16 Dec. 2005.

Piantadosi, C.A. and E.D. Thalmann. 2004. Pathology: whales, sonar and decompression sickness. **Nature** 428(6984).

Potter, J.R. 2004. A possible mechanism for acoustic triggering of decompression sickness symptoms in deep-diving marine mammals. Paper presented to the 2004 IEEE International Symposium on Underwater Technology, Taipei, Taiwan, 19-23 April 2004. Available at http://www.zifios.com/documentos-oficiales/documentos/Singapore_John_R_Potter_UT04.pdf

Reeves, R.R., E. Mitchell and H. Whitehead. 1993. Status of the northern bottlenose whale, *Hyperoodon ampullatus*. **Can. Field-Nat.** 107(4):490-508.

Reeves, R.R., R.J. Hofman, G.K. Silber and D. Wilkinson. 1996. Acoustic deterrence of harmful marine mammal-fishery interactions: proceedings of a workshop held in Seattle, Washington, 20-22 March 1996. NOAA Tech. Memo NMFS-OPR-10. U.S. Dep. Commerce, Nat. Mar. Fish. Serv. 70 p.

Richardson, W.J. and C.I. Malme. 1993. Man-made noise and behavioral responses. p. 631-700 *In*: J.J. Burns, J.J. Montague and C.J. Cowles (eds.), The bowhead whale. Spec. Publ. 2, Soc. Mar. Mammal., Lawrence, KS. 787 p.

Richardson, W.J. and B. Würsig. 1997. Influences of man-made noise and other human actions on cetacean behaviour. **Mar. Freshwat. Behav. Physiol.** 29(1-4):183-209.

Richardson, W.J., B. Würsig and C.R. Greene. 1986. Reactions of bowhead whales, *Balaena mysticetus*, to seismic exploration in the Canadian Beaufort Sea. **J. Acoust. Soc. Am.** 79(4):1117-1128.

Richardson, W.J., R.A. Davis, C.R. Evans, D.K. Ljungblad and P. Norton. 1987. Summer distribution of bowhead whales, *Balaena mysticetus*, relative to oil industry activities in the Canadian Beaufort Sea, 1980-84. **Arctic** 40(2):93-104.

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

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

Ridgway, S.H., D.A. Carder, R.R. Smith, T. Kamolnick, C.E. Schlundt and W.R. Elsberry. 1997. Behavioral responses and temporary shift in masked hearing threshold of bottlenose dolphins, *Tursiops truncatus*, to 1-second tones of 141 to 201 dB re 1 µPa. Tech. Rep. 1751. NRAD, RDT&E Div., Naval Command, Control & Ocean Surveillance Center, San Diego, CA. 27 p.

Riedman, M.L. 1983. Studies of the effects of experimentally produced noise associated with oil and gas exploration and development on sea otters in California. Rep. from Cent. Coastal Mar. Stud., Univ. Calif. Santa Cruz, CA, for U.S. Minerals Manage. Serv., Anchorage, AK. 92 p. NTIS PB86-218575

Riedman, M.L. 1984. Effects of sounds associated with petroleum industry activities on the behavior of sea otters in California. P. D-1 to D-12 *In*: C.I. Malme, P.R. Miles, C.W. Clark, P. Tyack and J.E. Bird, Investigations of the potential effects of underwater noise form petroleum industry activities on migrating gray whale behavior/Phase II: January 1984 migration. BBN Rep. 5586. Rep. from Bolt Beranek & Newman Inc., Cambridge, MA, for U.S. Minerals Manage. Serv., Anchorage, AK. Var. pag. NTIA PB86-218377.

Romano, T.A., M.J. Keogh, C.Kelly, P. Feng, L. Berk, C.E. Schlundt, D.A. Carder and J.J. Finneran. 2004. Anthropogenic sound and marine mammal health: measures of the nervous and immune systems before and after intense sound exposure. **Can. J. Fish. Aquat. Sci.** 61:1124-1134.

SACLANT. 1998. Estimation of cetacean hearing criteria levels. Section II, Chapter 7 *In*: SACLANTCEN Bioacoustics Panel Summary Record and Report. Report by NATO SACLANT Undersea Research Center. 60 p. Available at http://enterprise.spawar.navy.mil/spawarpublicsite/

Schlundt, C.E., J.J. Finneran, D.A. Carder and S.H. Ridgway. 2000. Temporary shift in masking hearing thresholds of bottlenose dolphins, *Tursiops truncatus*, and white whales, *Delphinapterus leucas*, after exposure to intense tones. **J. Acoust. Soc. Am.** 107(6):3496-3508.

Schusterman, R., D. Kastak, B. Southall and C. Kastak. 2000. Underwater temporary threshold shifts in pinnipeds: tradeoffs between noise intensity and duration. **J. Acoust. Soc. Am.** 108(5, Pt. 2):2515-2516.

Simmonds, M. P. and L.F. Lopez-Jurado. 1991. Whales and the military. **Nature** 351(6326):448.

Smultea, M.A., M. Holst, W.R. Koski and S. Stoltz. 2004. Marine mammal monitoring during Lamont-Doherty Earth Observatory’s seismic program in the Southeast Caribbean Sea and adjacent Atlantic Ocean, April–June 2004. LGL Rep. TA2822-26. Rep. From LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 106 p.

Stone, C.J. 2003. The effects of seismic activity on marine mammals in UK waters 1998-2000. JNCC Report 323. Joint Nature Conservancy, Aberdeen, Scotland. 43 p.

Terhune, J.M. 1999. Pitch separation as a possible jamming-avoidance mechanism in underwater calls of bearded seals (*Erignathus barbatus*). **Can. J. Zool.** 77(7):1025-1034.

Thompson, D., M. Sjöberg, E.B. Bryant, P. Lovell and A. Bjørge. 1998. Behavioural and physiological responses of harbour (*Phoca vitulina*) and grey (*Halichoerus grypus*) seals to seismic surveys. p. 134 *In:* World Marine Mammal Science Conf. Abstract volume, Monaco. 160 p.

Tolstoy, M., J. Diebold, S. Webb, D. Bohnenstiehl and E. Chapp. 2004a. Acoustic calibration measurements. Chapter 3 *In:* W.J. Richardson (ed.), Marine mammal and acoustic monitoring during Lamont-Doherty Earth Observatory's acoustic calibration study in the northern Gulf of Mexico, 2003. Revised ed. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. [Advance copy of updated Chapter 3.]

Tolstoy, M., J.B. Diebold, S.C. Webb, D.R. Bohenstiehl, E. Chapp, R.C. Holmes and M. Rawson. 2004b. Broadband calibration of R/V *Ewing* seismic sources. **Geophys. Res. Lett.** 31:L14310.

Tyack, P., M. Johnson and P. Miller. 2003. Tracking responses of sperm whales to experimental exposures of airguns. p. 115-120 *In:* A.E. Jochens and D.C. Biggs (eds.), Sperm whale seismic study in the Gulf of Mexico/Annual Report: Year 1. OCS Study MMS 2003-069. Rep. from Texas A&M Univ., College Station, TX, for U.S. Minerals Manage. Serv., Gulf of Mexico OCS Reg., New Orleans, LA.

Urick, R.J. 1983. Principles of underwater sound, 3rd ed. McGraw-Hill, New York, NY. 423 p.

Watkins, W.A. 1986. Whale reactions to human activities in Cape Cod waters. **Mar. Mamm. Sci.** 2(4):251-262.

Watkins, W.A. and W.E. Schevill. 1975. Sperm whales (*Physeter catodon*) react to pingers. **Deep-Sea Res.** 22(3):123-129.

Watkins, W.A., K.E. Moore and P. Tyack. 1985. Sperm whale acoustic behaviors in the southeast Caribbean. **Cetology** 49:1-15.

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

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

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

Yoder, J.A. 2002. Declaration of James A. Yoder in opposition to plaintiff's motion for temporary restraining order, 28 October 2002. Civ. No. 02-05065-JL. U.S. District Court, Northern District of California, San Francisco Division.