Request by ION Geophysical for an Incidental Harassment Authorization to Allow the Incidental Take of Marine Mammals during a Marine Seismic Survey in the Arctic Ocean, October–December 2012

submitted by

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to

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February 2012
Revised June 2012

LGL Document P1236-1

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SUMMARY

The geophysical survey proposed by ION Geophysical (ION) will occur in late fall after many arctic marine mammal species have typically migrated out of the Beaufort Sea and northern Chukchi Sea. The marine mammal species most likely to occur in the survey area at this time is ringed seal; however, several other arctic marine mammal species may also be encountered during the proposed survey. The only species listed as endangered under the U.S. Endangered Species Act (ESA) likely to be encountered is the bowhead whale; however, most bowheads will have migrated south into the southern Chukchi Sea and Bering Sea by the time of the survey. ION is planning to implement a marine mammal monitoring and mitigation program to minimize the impacts of the proposed activity on marine mammals during the proposed seismic activity, and, to the extent possible, document the nature and magnitude of any effects.

The items required to be addressed in a request for an Incidental Harassment Authorization (IHA) 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 mammal species occurring in the proposed survey area, and proposed measures to mitigate any potential injurious effects on marine mammals. A related application has been submitted to the U.S. Fish & Wildlife Service with regard to potential effects on species managed by USFWS – the Pacific walrus and polar bear.

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.

The specific activities to be addressed consist of a geophysical (seismic reflection/refraction) survey and related vessel operations to be conducted primarily in the Alaskan Beaufort and Chukchi seas from October to December 2012. The primary survey area extends from the U.S.–Canadian border in the east to Point Barrow in the west. Two survey lines extend west of Point Barrow into the northern Chukchi Sea and three short tie lines are proposed near the U.S.–Russian border (Fig. 1). The bathymetry of the proposed survey area ranges from shallow (<20 m) to relatively deep (>3500 m) water over the continental shelf, the continental slope, and the abyssal plain.

The survey will be conducted from the seismic vessel *Geo Arctic* escorted by the *Polar Prince*, a medium class (100A) icebreaker. The survey grid consists of ~7175 km of transect line, not including transits when the airguns are not operating. There may be small amounts of additional seismic operations associated with airgun testing, start up, and repeat coverage of any areas where initial data quality is substandard. The seismic source towed by the *Geo Arctic* will be an airgun array consisting of 26 active Sercel G-gun airguns with a total volume of 4450 in^3. A single hydrophone streamer 4.5–9 km in length, depending on ice conditions, will be towed by the *Geo Arctic* to record the returning seismic signals.

The survey vessels will access the survey area from Canadian waters in late September to begin data collection on or after 1 October. After completion of the survey, or when ice and weather conditions dictate, the vessels will exit to the south transiting through the Chukchi and Bering seas. The *Polar Prince* may be used to perform an at-sea refueling (bunkering) operation to supply as much as 500 metric tons of Arctic diesel to the *Geo Arctic*. The *Polar Prince* will carry that fuel onboard at the start of the operation and it would be transferred to the *Geo Arctic* if/when necessary. Depending on its own fuel consumption, the *Polar Prince* may then transit to Tuktoyuktuk, Canada to take on additional fuel for itself. Once the *Polar Prince* returns to the Geo Arctic the survey would continue. The entire refueling operation would therefore involve one fuel transfer and *potentially* one transit to and from Tuktoyuktuk. The refueling operation would likely take place in late October, at which time the *Geo Arctic* would likely be in the eastern or east-central Alaskan Beaufort Sea.

ION's geophysical survey has been designed and scheduled to minimize potential effects to marine mammals, bowhead whales in particular, and subsistence users. For mitigation and operational reasons the survey area has been bisected by a line that runs from 70.5° N, 150.5° W to 73° N, 148° W (Fig. 1). Weather and ice permitting, ION plans to begin survey operations east of the line described above (eastern survey area; Fig. 1) and in offshore waters (>1000 m) where bowheads are expected to be least abundant in early October. This operational plan is based on the fact that only ~2% of bowhead whales observed by MMS aerial surveys 1979–2007 occurred in areas of water depth >1000 m (MMS 2010), and on average ~97% of bowheads have passed through the eastern U.S. Beaufort Sea by 15 Oct (Miller et al. 2002). The survey will then progress to shallower waters in the eastern survey area before moving to the western survey area (Fig. 1) in late October or early November.

Ice conditions are expected to range from open water to 10/10 ice cover. However, the survey cannot take place in thick multi-year ice as both the icebreaker and seismic vessel must make continuous forward progress at 3–4 kts. In order for the survey to proceed, areas of high ice concentration can only consist of mostly newly forming juvenile first year ice or young first year ice less than 0.5 m (1–1.5 ft) thick. Sounds generated by the icebreaker and seismic vessel moving through these relatively light ice conditions are expected to be far below the high sound levels often attributed to icebreaking. These high sound levels (>200 dB re 1 µPa [rms]) have been recorded from icebreakers during backing and ramming operations in very heavy ice conditions and are created by cavitation of the propellers as the vessel is slowed by the ice or reverses direction (Erbe and Farmer 1998; Roth and Schmidt 2010).

Acoustic Sources

Seismic Airgun Array

The seismic source used during the project will be an airgun array consisting of 28 Sercel G-gun airguns, of which 26 will be active and have a total discharge volume of 4450 in^3. The 28 airguns will be distributed in two sub-arrays with 14 airguns per sub-array. Individual airgun sizes range from 70 to 380 in^3. Airguns will be operated at 2000 psi. The seismic array and a single hydrophone streamer 4.5–9 km in length will be towed behind the *Geo Arctic*. Additional specifications of the airgun array are provided in Appendix B.

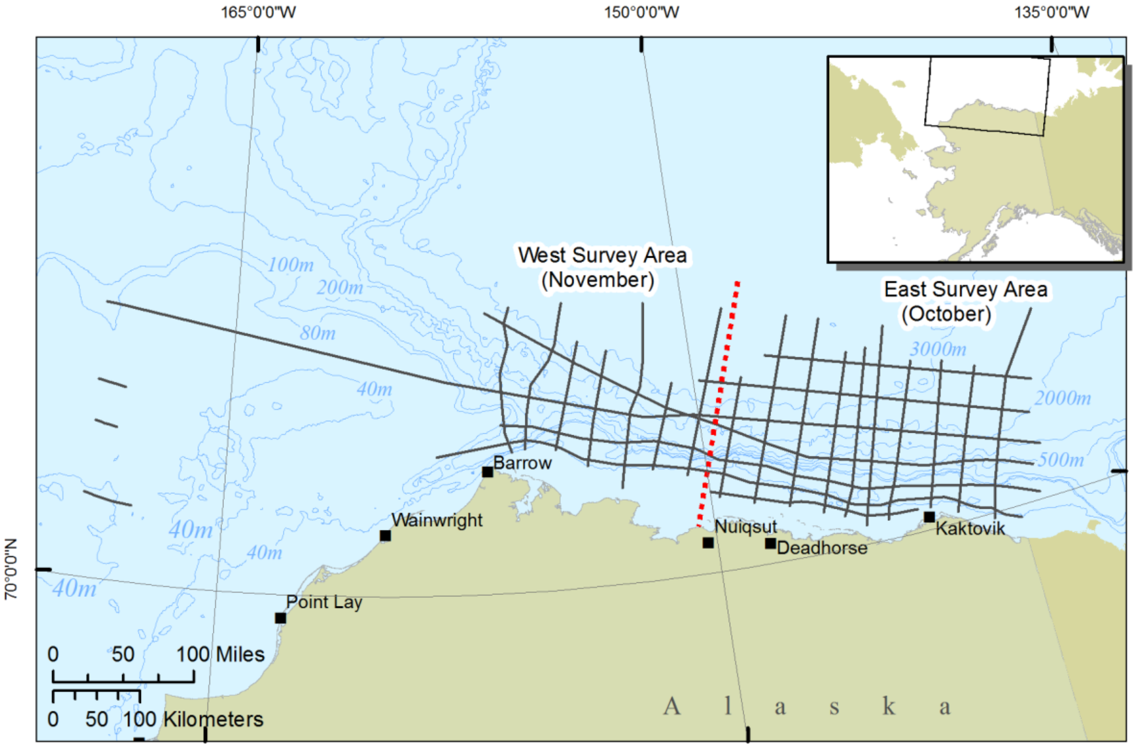

FIGURE 1. Proposed seismic survey lines for ION 2D seismic survey, Oct-Dec 2012. The red dashed line indicates the division between the "east survey area" and the "west survey area".

Echo sounders

Both vessels will operate industry standard echo sounder/fathometer instruments for continuous measurements of water depth while underway. These instruments are used by all large vessels to provide routine water depth information to the vessel crew. Navigation echo sounders send a single, narrowly focused, high frequency acoustic signal directly downward to the sea floor. The sound energy reflected off the sea floor returns to the vessel where it is detected by the instrument and the depth is calculated and displayed to the user. Source levels of navigational echo sounders of this type are typically in the 180–200 dB re 1 µPA-m (Richardson et al. 1995a).

The *Geo Arctic* will use one navigational echo sounder during the project. The downward facing single-beam Simrad EA600 operates at frequencies ranging from 38 to 200 kHz with an output power of 100–2000 Watts. Pulse durations are between 0.064 and 4.096 milliseconds and the pulse repetition frequency (PRF or ping rate) depends on the depth range. The highest PRF at shallow depths is about 40 pings per second. It can be used for water depths up to 4000 m and provides up to 1 cm resolution.

The *Polar Prince* will use one echo sounder, an ELAC LAZ-72. The LAZ-72 has an operating frequency of 30 kHz. The ping rate depends on the water depth and the fastest rate, which occurs in shallow depths, is about 5 pings per second.

II. DATES, DURATION, AND REGION OF ACTIVITY

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

The proposed geophysical survey will be conducted for ~76 days from ~1 October to 15 December 2012. Both the *Geo Arctic* and the *Polar Prince* will leave from Tuktoyaktuk, Canada, during late September and enter the Alaskan Beaufort Sea from Canadian waters. The survey area will be bounded approximately by 138º to 169º W longitude and 70º to 73º N latitude in water depths ranging from <20 to >3500 m (Fig. 1). For mitigation and operational reasons the survey area has been bisected by a line that runs from 70.5° N, 150.5° W to 73° N, 148° W (Fig. 1). Weather and ice permitting, ION plans to begin survey operations east of the line (eastern survey area; Fig. 1) in offshore waters (>1000 m) where bowheads are expected to be least abundant in early October. The survey will then progress to shallower waters in the eastern survey area before moving to the west survey area (Fig. 1) in late October or early November. The vessels will depart the region to the south via the Chukchi and Bering seas and arrive in Dutch Harbor in mid- to late December.

III. SPECIES AND NUMBERS OF MARINE MAMMALS IN AREA

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

Marine mammals that occur in the proposed survey area belong to three taxonomic groups: odontocetes (toothed cetaceans, such as beluga whale), mysticetes (baleen whales), and carnivora (pinnipeds and polar bears). Cetaceans and pinnipeds (except Pacific walrus) are the subject of this IHA application to NMFS. Pacific walrus and polar bear are managed by the U.S. Fish & Wildlife Service (USFWS). A separate application for this survey has been submitted to USFWS for incidental "takes" specific to walruses and polar bears and these species are not discussed further in this IHA application.

Marine mammal species under the jurisdiction of NMFS which are known to or may occur in the seismic survey area at some point during the year include nine cetacean species and four species of pinnipeds (Table 1). Three of the cetacean species, the bowhead, humpback and fin whales, are listed as endangered under the ESA. The bowhead whale is more common in the survey area than other endangered species and the most likely endangered species to be encountered during the proposed survey activities. However, bowhead whales typically migrate out of the Beaufort Sea during the fall. Based on a small number of sightings in the Chukchi Sea during summer months, the fin whale is unlikely to be encountered during the proposed survey. Humpback whales are also uncommon in the Chukchi Sea and normally do not occur in the Beaufort Sea. Several humpback sightings were recorded during vessel-based surveys in the Chukchi Sea in 2007 (three sightings) and 2008 (one sighting; Haley et al. 2010). The only known occurrences of humpback whales in the Beaufort Sea include a sighting of a cow and calf reported and photographed in 2007 (Green et al. 2007), and a single humpback near Barrow reported during aerial surveys by NMFS (Rugh 2009). Based on the low number of sightings in the Chukchi and Beaufort seas, and the late fall timing of this survey, humpback whales would be unlikely to occur in the vicinity of the proposed geophysical activities. Two of the pinniped species manage by NMFS, the ringed seal and bearded seal, have been proposed for listing as threatened under the ESA. Most bearded seals and many ringed seals will have likely migrated out of the survey area by the time of the proposed activities; although some individuals will have remained, especially in shallower coastal waters.

To avoid further 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.

The marine mammal species under NMFS jurisdiction most likely to occur in the seismic survey area at the time of the proposed survey include two cetacean species (beluga and bowhead whales), and two pinniped species (ringed and bearded seals). It is possible that some bowhead whales may be encountered as they migrate out of the area, particularly in the portion of the survey area where water depths are <200 m. Beluga whales are most likely to be encountered farther offshore than bowheads.

The ringed seal is the most abundant marine mammal in the proposed survey area. Although bearded seals typically migrate south in the fall, it is possible that small numbers of them may be present in the survey area. Most other marine mammal species have typically migrated south into the Bering Sea by the time this survey will take place.

TABLE 1. The habitat, abundance (in the Beaufort Sea, if available), and conservation status of marine mammals inhabiting the proposed survey area.

Species	**Habitat**	**Abundance**	**ESA[1]**	**IUCN[2]**	**CITES[3]**
Odontocetes Beluga whale (*Delphinapterus leucas*) (Eastern Chukchi Sea Stock)	Offshore, Coastal, Ice edges	3710[4]	Not listed	NT	–
Beluga whale (Beaufort Sea Stock)	Offshore, Coastal, Ice edges	39,257[5]	Not listed	NT	–
Harbor Porpoise (*Phocoena phocoena*) (Bering Sea Stock)	Coastal, inland waters, shallow offshore waters	Uncommon	Not listed	LC	–
Killer whale (*Orcinus orca*)	Widely distributed	Rare	Not listed	DD	–
Narwhal (*Monodon monoceros*)	Offshore, Ice edge	Rare[6]	Not listed	NT	–
Mysticetes Bowhead whale (*Balaena mysticetus*)	Pack ice & coastal	10,545[7] 12,631[8]	Endangered	LC	I
Gray whale (*Eschrichtius robustus*) (eastern Pacific population)	Coastal, lagoons	Uncommon (Beaufort) 488[9] (Chukchi)	Not listed	LC	I
Fin whale (*Balaenoptera physalus*)	Slope, mostly pelagic	Rare (Chukchi)	Endangered	LC	I
Minke whale (*Balaenoptera acutorostrata*)	Shelf, coastal	Rare	Not listed	LC	I
Humpback whale (*Megaptera novaeangliae*)	Shelf, coastal	Rare	Endangered	LC	I
Pinnipeds Bearded seal (*Erignathus barbatus*)	Pack ice, shallow offshore waters	250,000-300,000[10] 155,000[11]	Threatened	LC	–

Species	Habitat	Abundance	ESA[1]	IUCN[2]	CITES[3]
Ribbon seal (*Histriophoca fasciata*)	Offshore, pack ice	Rare (Beaufort) 90-100,000[12]	Not Listed	DD	–
Ringed seal (*Pusa hispida*)	Landfast & pack ice, offshore	18,000 [13] 208,000-252,000[14]	Threatened	LC	–
Spotted seal (*Phoca largha*)	Pack ice, coastal haulouts	59,214[15] 1000[16]	Arctic pop. segments not listed	DD	–

[1] U.S. Endangered Species Act.

[2] IUCN Red List of Threatened Species (2010). Codes for IUCN classifications: CR = Critically Endangered; EN = Endangered; VU = Vulnerable; NT = Near Threatened; LC = Least Concern; DD = Data Deficient.

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

[4] Allen and Angliss (2011)

[5] Beaufort Sea population (IWC 2000, Allen and Angliss 2011).

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

[7] 2001 Population Estimate (Zeh and Punt 2005)

[8] 2004 Population estimate (Koski et al. 2009).

[9] Southern Chukchi Sea and northern Bering Sea (Clark and Moore 2002).

[10] Popov (1976), Burns (1981b).

[11] Beringia Distinct Population Segment (NMFS 2010a).

[12] Burns, J.J. 1981a.

[13] Beaufort Sea minimum estimate with no correction factor based on aerial surveys in 1996-1999 (Frost et al. 2002 *in* Allen and Angliss 2011).

[14] Alaskan Beaufort Sea population estimate (Amstrup 1995).

[15] Alaska stock based on haul-outs (Allen and Angliss 2011).

[16] Alaska Beaufort Sea population (USDI/MMS 1996).

Seven additional cetacean species— narwhal, killer whale, harbor porpoise, gray whale, minke whale, fin whale, and humpback whale —could occur in the project area; however, due to the late autumn timing of the proposed survey, occurrence of these species during the survey period is unlikely. The gray whale occurs regularly in continental shelf waters along the Chukchi Sea coast in summer and to a lesser extent along the Beaufort Sea coast. Recent evidence from monitoring activities in the Chukchi and Beaufort seas during industry seismic surveys suggests that the harbor porpoise and minke whale, which have been considered uncommon or rare in the Chukchi and Beaufort seas, may be increasing in numbers in these areas (Funk et al. 2010). Small numbers of killer whales have also been recorded during recent industry surveys, along with a few sightings of fin and humpback whales. The narwhal occurs in Canadian waters and occasionally in the Beaufort Sea, but is rare there and not expected to be encountered. Each of these species is uncommon or rare in the Beaufort Sea, particularly during early winter, and relatively few if any encounters with these species are expected during the seismic program.

Additional pinniped species under NMFS jurisdiction that could be encountered during the proposed geophysical survey include bearded, spotted and ribbon seals. Bearded seals are common in the Beaufort Sea during summer but typically migrate out of the area during fall. Small numbers of them may still be present at the start of the proposed survey. Spotted seals are more abundant in the Chukchi Sea and occur in small numbers in the Beaufort Sea. The ribbon seal is uncommon in the Chukchi Sea and there are few reported sightings in the Beaufort Sea.

Odontocetes

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 80º N (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).

Belugas often migrate in groups of 100 to 600 animals (Braham and Krogman 1977) or more, although smaller groups are also commonly seen during migrations and at other times of the year. Pod structure in beluga groups is thought to be along matrilineal lines, with males forming separate aggregations. Hunters have reported that belugas form family groups with whales of different ages traveling together (Huntington 2000).

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

The ***Beaufort Sea population*** was estimated to contain 39,258 individuals as of 1992 (Allen and Angliss 2011). This estimate was based on the application of a sightability correction factor of 2× to the 1992 uncorrected census of 19,629 individuals made by Harwood et al. (1996). This estimate was obtained from a partial survey of the known range of the Beaufort Sea population and may be an underestimate of the true population size. This population is not considered by NMFS to be a strategic stock and is believed to be stable or increasing (DeMaster 1995).

Beluga whales of the Beaufort stock winter in the Bering Sea, summer in the eastern Beaufort Sea, and migrate in offshore waters of western and northern Alaska (Allen and Angliss 2011). The majority of belugas in the Beaufort stock migrate into the Beaufort Sea in April or May, although some whales may pass Point Barrow as early as late March and as late as July (Braham et al. 1984; Ljungblad et al. 1984; Richardson et al. 1995a).

Much of the Beaufort Sea seasonal population enters the Mackenzie River estuary for a short period during July–August to molt their epidermis, but they spend most of the summer in offshore waters of the eastern Beaufort Sea, Amundsen Gulf and more northerly areas (Davis and Evans 1982; Harwood et al. 1996; Richard et al. 2001). Belugas are rarely seen in the central Alaskan Beaufort Sea during the early summer, but a number were reported there during early July from aerial surveys in 2008 (Christie et al. 2010). During late summer and autumn, beluga whales migrate westward far offshore near the pack ice (Frost et al. 1988; Hazard 1988; Clarke et al. 1993; Miller et al. 1999) and tend to favor slope waters 200–2000 m in depth. As whales approach the Chukchi Sea, the preferred slope waters are closer to shore as a result of Barrow Canyon. In 2009, the greatest numbers of belugas observed during BWASP surveys were sighted in this Barrow Canyon area (Clarke et al. 2011a). During fall aerial surveys in the Alaskan Beaufort Sea, Christie et al. (2010) reported the highest beluga sighting rates during the first two weeks of September and in the northern part of their survey area. However, during fall BWASP surveys in the 2007–2010 period, the highest sighting rates and the most number of individual belugas were sighted in October in the Barrow Canyon area (Ferguson, M. pers. comm.)

Moore (2000) and Moore et al. (2000b) suggested 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). Christie et al. (2010) reported higher beluga sighting rates at locations >60 km offshore than at locations nearer shore during aerial surveys in the Alaskan Beaufort Sea in 2006–2008. Belugas were not recorded, however, during arctic cruises by the *Healy* in 2005 or 2006 (Haley 2006; Haley and Ireland 2006). The main fall migration corridor of beluga whales is ~100+ km north of the coast. Satellite-linked telemetry data show that some belugas of this population migrate west considerably farther offshore, as far north as 76º to 78ºN latitude (Richard et al. 1997, 2001), which would be well beyond the range of the proposed survey. It is possible that beluga whales from the Beaufort Sea population could be encountered during the proposed survey, but most of these whales will have migrated into the Chukchi Sea by the time the vessels reach the western Beaufort Sea.

The most recent estimate of the ***eastern Chukchi Sea*** population is 3710 animals (Allen and Angliss 2011). This estimate was based on surveys conducted in 1989–1991. Survey effort was concentrated on the 170-km long Kasegaluk Lagoon where belugas are known to occur during the open-water season. The actual number of beluga whales recorded during the surveys was much lower. Correction factors to account for animals that were underwater and for the proportion of newborns and yearlings that were not observed due to their small size and dark coloration were used to calculate the estimate. The calculation was considered to be a minimum population estimate for the eastern Chukchi Sea stock because the surveys on which it was based did not include offshore areas where belugas are also likely to occur. This population is considered to be stable. It is assumed that beluga whales from the eastern Chukchi stock winter in the Bering Sea (Allen and Angliss 2011).

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

During aerial surveys in nearshore areas ~23 mi (~37 km) offshore in the Chukchi Sea in 2006 and 2007, peak beluga sighting rates were recorded in July. Lowest monthly sighting rates were recorded in September (Thomas et al. 2010). When data from the two years were pooled, beluga whale sighting rates and number of individuals were highest in the band 16-22 mi (25-35 km) offshore. However the largest single groups were sighted at locations near shore in the band within 3 mi (5 km) of the shoreline.

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 the 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). In 2007, approximately 70 belugas were also harvested at Kivalina located southeast of Point Hope.

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

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 2008). Innes et al. (2002) estimated a population size of 45,358 narwhals in the Canadian Arctic although little of the area was surveyed. There are scattered records of narwhals in Alaskan waters where the species is considered extralimital (Reeves et al. 2002). Thus, it is possible, but unlikely, that individuals could be encountered in the proposed survey area.

Killer Whale (Orcinus orca)

Killer whales are cosmopolitan and globally fairly abundant. The killer whale is very common in temperate waters, but it also frequents the tropics and waters at high latitudes. Killer whales appear to prefer coastal areas, but are also known to occur in deep water (Dahlheim and Heyning 1999). The greatest abundance is thought to occur within 800 km of major continents (Mitchell 1975) and the highest densities occur in areas with abundant prey. Both resident and transient stocks have been described. The resident and transient types are believed to differ in several aspects of morphology, ecology, and behavior including dorsal fin shape, saddle patch shape, pod size, home range size, diet, travel routes, dive duration, and social integrity of pods (Allen and Angliss 2011).

Killer whales are known to inhabit almost all coastal waters of Alaska, extending from southeast Alaska through the Aleutian Islands to the Bering and Chukchi seas (Allen and Angliss 2011). Killer whales probably do not occur regularly in the Beaufort Sea, although sightings have been reported (Leatherwood et al. 1986; Lowry et al. 1987). George et al. (1994) reported that they and local hunters see a few killer whales at Point Barrow each year. Killer whales are more common southwest of Barrow in the southern Chukchi Sea and the Bering Sea. Based on photographic techniques, ~100 animals have been identified in the Bering Sea (ADFG 1994). Killer whales from either the North Pacific resident or transient stock could occur in the Chukchi Sea during the summer, however winter occurrence is more unlikely. Marine mammal observers (MMOs) onboard industry vessels in the Chukchi Sea recorded five killer whale sightings in summer 2006–2008 (Haley et al. 2010). MMOs onboard industry vessels did not record any killer whale sighting in the Beaufort Sea in 2006–2008 (Savarese et al. 2010). Based on the scarcity of killer whale sightings in the Beaufort Sea and the late fall timing of the survey in the Chukchi, it is unlikely that killer whales will be encountered.

Harbor Porpoise (Phocoena phocoena)

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

The subspecies *P. p. vomerina* ranges from the Chukchi Sea, Pribilof Islands, Unimak Island, and the south-eastern shore of Bristol Bay south to San Luis Obispo, California. Point Barrow, Alaska, is the approximate northeastern extent of the regular range (Suydam and George 1992), though there are extralimital records east to the mouth of the Mackenzie River in the Northwest Territories, Canada, (LGL Limited, unpubl. data) and recent sightings in the Beaufort Sea in the vicinity of Prudhoe Bay during surveys in 2007 and 2008 (Christie et al. 2010). MMOs onboard industry vessels reported one harbor porpoise sighting in the Beaufort Sea in 2006 and no sightings were recorded in 2007 or 2008 (Savarese et al. 2010). Monnett and Treacy (2005) did not report any harbor porpoise sightings during aerial surveys in the Beaufort Sea from 2002 through 2004.

Although separate harbor porpoise stocks for Alaska have not been identified, Alaskan harbor porpoises have been divided into three groups for management purposes. These groups include animals from southeast Alaska, Gulf of Alaska, and Bering Sea populations. Chukchi Sea harbor porpoises belong to the Bering Sea group which includes animals from Unimak Pass northward. Based on aerial surveys in 1999, the Bering Sea population was estimated at 48,215 animals, although this estimate is likely conservative as the surveyed area did not include known harbor porpoise range near the Pribilof Islands or waters north of Cape Newenham (~55°N; Allen and Angliss 2010). Suydam and George (1992) suggested that harbor porpoises occasionally occur in the Chukchi Sea and reported nine records of harbor porpoise in the Barrow area in 1985–1991.

More recent vessel-based surveys in the Chukchi Sea found that the harbor porpoise was one of the most abundant cetaceans during summer and fall in 2006–2008 (Ireland et al. 2008; Haley et al. 2010). Although these recent sightings suggest that harbor porpoise numbers may be increasing in the relatively shallow waters of the Chukchi Sea, no recent information is available on the their status in deeper offshore waters. Harbor porpoises were not recorded during *Healy* cruises in the Arctic in 2005 or 2006 (Haley and Ireland 2006; Haley 2006). Harbor porpoises are not expected to be encountered during the proposed survey, although a few could be present if ice conditions are favorable.

Mysticetes

Bowhead Whale (Balaena mysticetus)

Bowhead whales only occur at high latitudes in the northern hemisphere and have a disjunct circumpolar distribution (Reeves 1980). The bowhead is one of only three whale species that spend their entire lives in the Arctic. Bowhead whales are found in four areas: the western Arctic (Bering, Chukchi, and Beaufort seas) of northeastern Russia, Alaska and northwestern Canada; the Canadian High Arctic and West Greenland (Nunavut, Baffin Bay, Davis Strait, and Hudson Bay); the Okhotsk Sea (eastern Russia); and the Northeast Atlantic from Spitzbergen westward to eastern Greenland. Those four stocks are recognized for management purposes. The largest population is the Western Arctic or Bering–Chukchi–Beaufort (BCB) stock, which includes whales that winter in the Bering Sea and migrate through the Bering Strait, Chukchi Sea and Alaskan Beaufort Sea to the Canadian Beaufort Sea, where they feed during the summer. These whales migrate west through the Alaskan Beaufort Sea in the fall as they return to wintering areas in the Bering Sea. Visual and satellite tracking data show that some bowhead whales continue migrating west past Barrow and through the Chukchi Sea to Russian waters before turning southeast toward the Bering Sea (Moore et al. 1995; Mate et al. 2000; Quakenbush 2010). Some bowheads reach ~75ºN latitude during the westward fall migration (Quakenbush 2010).

The pre-exploitation population of bowhead whales in the Bering, Chukchi, and Beaufort seas is estimated to have been 10,400-23,000 whales. Commercial whaling activities may have reduced this population to perhaps 3000 animals (Woodby and Botkin 1993). Up to the early 1990s, the population size was believed to be increasing at a rate of about 3.2% per year (Zeh et al. 1996) despite annual subsistence harvests of 14–74 bowheads from 1973 to 1997 (Suydam et al. 1995). A census in 2001 yielded an estimated annual population growth rate of 3.4% (95% CI 1.7–5%) from 1978 to 2001 and a population size (in 2001) of ~10,470 animals (George et al. 2004, subsequently revised to 10,545 by Zeh and Punt [2005]). A population estimate from photo identification data collected in 2004 was 11,800

(Koski et al. 2009), which further supports the estimated 3.4 percent population growth rate. Assuming a continuing annual population growth of 3.4%, the 2011 bowhead population may number around 14,732 animals. The large increases in population estimates that occurred from the late 1970s to the early 1990s were partly a result of actual population growth, but were also partly attributable to improved census techniques (Zeh et al. 1993). Although apparently recovering well, the BCB bowhead population is currently listed as endangered under the ESA and is classified as a strategic stock by NMFS and depleted under the MMPA (Allen and Angliss 2011).

The BCB stock of bowhead whales winter in the central and western Bering Sea and many of them summer in the Canadian Beaufort Sea (Moore and Reeves 1993). Spring migration through the Chukchi and the western Beaufort Sea occurs through offshore ice leads, generally from March 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 midsummer. After feeding primarily in the Canadian Beaufort Sea and Amundsen Gulf, bowheads migrate westward across the Beaufort Sea from late August through mid- or late October.

Bowhead activity in the Beaufort Sea in fall has been well studied in recent years. Fall migration through Alaskan waters is primarily during September and October. However, small numbers of bowheads have been seen or heard offshore from the Prudhoe Bay region during late August (Treacy 1993; LGL and Greeneridge 1996; Greene 1997; Greene et al. 1999; Blackwell et al. 2004, 2008; Greene et al. 2007). Satellite tracking of bowheads has also shown that some whales move to the Chukchi Sea prior to September (Quakenbush et al. 2010). In 2007 the Minerals Management Service (MMS; now BOEMRE) and the National Marine Mammal Laboratory (NMML) initiated the Bowhead Whale Feeding Ecology Study (BOWFEST) focusing on late summer oceanography and prey densities relative to bowhead distribution (Rugh et al. 2009).

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

In late summer/autumn, although a few bowheads are sometimes present in late August, the main concentration of westward-migrating bowhead whales typically reaches the Kaktovik and Cross Island areas in early September, when the subsistence hunts for bowheads typically begin in those areas (Kaleak 1996; Long 1996; Galginaitis and Koski 2002; Galginaitis and Funk 2004, 2005; Koski et al. 2005). In recent years the hunts at those two locations have usually ended by mid- to late September.

Westbound bowheads typically reach the Barrow area in mid-September, and are in that area until late October (Brower 1996; Quakenbush et al. 2010). Autumn bowhead whaling near Barrow normally begins in mid-September to early October, but may begin as early as August if whales are observed and ice conditions are favorable (USDI/BLM 2005). Whaling near Barrow can continue into October, depending on the quota and conditions.

Over the years, local residents have reported small numbers of bowhead whales feeding off Barrow or in the pack ice off Barrow during the summer. Bowhead whales that are thought to be part of the Western Arctic stock may also occur in small numbers in the Bering and Chukchi seas during the summer (Moore 1992; Rugh et al. 2003). Thomas et al. (2010) reported bowhead sightings during summer aerial surveys in nearshore areas of the Chukchi Sea from 2006–2008. All sightings were recorded in the northern portion of the study area north of 70ºN latitude. Peak monthly bowhead sighting rates, however, were highest in October and November and lowest in July–September. A few bowhead whales were also recorded during vessel-based surveys in summer 2008 in the Chukchi Sea (Funk et al. 2010). Observers from the NMML reported 19 summer bowhead sightings in the Chukchi Sea during aerial surveys from 26 June through 26 July 2009 suggesting that some bowheads may summer in the Chukchi Sea (COMIDA 2009). Only one bowhead sighting was reported during similar surveys in 2008, and that sighting was recorded later in the summer season (22 August). Sekiguchi et al. (2008) reported one sighting of an aggregation of ~30 bowheads during vessel-based operations about 130 km north of Cape Lisburne on 9 August 2007. Bowhead whales were not reported by vessel-based observers on the *Healy* during arctic cruises in 2005 and 2006 (Haley and Ireland 2006; Haley 2006).

It is possible that bowhead whales could be encountered in October as late-migrating bowheads transit through the central Beaufort Sea. However, recent acoustic and satellite tracking studies suggest that most bowheads will have migrated west of Barrow by mid October and thus out of the proposed eastern survey area before the survey in that section is underway (ADFG 2010). To minimize the chance of encounters with migrating bowhead whales the proposed survey will begin in offshore waters deeper than 1000 m, move into continental shelf waters at the eastern end of the study area in mid-October, and then progress westward. Under this survey design it is expected that encounters with bowhead whales will be much less frequent (if they occur at all) than would occur during a survey in the open water season.

Gray Whale **(Eschrichtius robustus)**

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

Eastern Pacific gray whales calve in the protected waters along the west coast of Baja California and the east coast of the Gulf of California from January to April (Swartz and Jones 1981; Jones and Swartz 1984). At the end of the calving season, most of these gray whales migrate about 8000 km, generally along the west coast of North America, to the main summer feeding grounds in the northern Bering and Chukchi seas (Tomilin 1957; Rice and Wolman 1971; Braham 1984; Nerini 1984; Moore et al. 2003; Bluhm et al. 2007). Most gray whales begin southward migration in November with breeding and conception occurring in early December (Rice and Wolman 1971).

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

Gray whales occur fairly often near Point Barrow, but historically only a small number of gray whales have been sighted in the Beaufort Sea east of Point Barrow. Hunters at Cross Island (near Prudhoe Bay) took a single gray whale in 1933 (Maher 1960). Only one gray whale was sighted in the central Alaskan Beaufort Sea during the extensive aerial survey programs funded by BOEM and industry from 1979 to 1997. However, during September 1998, small numbers of gray whales were sighted on several occasions in the central Alaskan Beaufort Sea (Miller et al. 1999; Treacy 2000). More recently a single sighting of a gray whale was made on 1 August 2001 near the Northstar production island (Williams and Coltrane 2002). Several gray whale sightings were reported during both vessel-based and aerial surveys in the Beaufort Sea in 2006–2008 (Savarese et al. 2010; Christie et al. 2010). Several single gray whales have been seen farther east in the Canadian Beaufort Sea (Rugh and Fraker 1981), indicating that small numbers must travel through the Alaskan Beaufort during some summers.

In recent years, ice conditions have become lighter near Barrow, and gray whales may have become more common there and perhaps in the Beaufort Sea. However, no gray whales were sighted during cruises north of Barrow in 2002, 2005 or 2006 (Harwood et al. 2005; Haley and Ireland 2006; Haley 2006). During aerial surveys of the Chukchi Sea in 2008–2010, 13 on-transect sightings of gray whales were made in the area east and northeast of Pt. Barrow in October (Clarke et al. 2011b).

Few gray whales are expected to be encountered during the proposed survey. Gray whales are not commonly observed in the Beaufort Sea, and it is unlikely that many gray whales will be present in the northern Chukchi Sea during planned operations there in November.

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. Allen and Angliss (2011) recognize two minke whale stocks in U.S. waters: (1) the Alaska stock, and (2) the California/Oregon/Washington stock. There is no abundance estimate for the Alaska stock. Provisional estimates of minke whale abundance based on surveys in 1999 and 2000 are 810 and 1003 whales in the central-eastern and south-eastern Bering Sea, respectively (Moore et al. 2002). These estimates have not been corrected for animals that may have been submerged or otherwise missed during the surveys, and only a portion of the range of the Alaskan stock in the central eastern and southeastern Bering Sea was surveyed.

The level of minke whale use of the Chukchi Sea is unknown. Leatherwood et al. (1982, *in* Allen and Angliss 2010) indicated that minke whales are not considered abundant in any part of their range, but that some individuals venture north of the Bering Strait in summer. Minke whales have recently been observed in the Chukchi Sea and a few sightings have been reported in the Beaufort Sea. Haley et al. (2010) reported 39 minke whale sightings during industry activities in the Chukchi Sea in 2006–2008 while Savarese et al. (2010) reported two minke whale sightings in the Beaufort Sea during the same period. No minke whale sighting were reported during Arctic cruises by the *Healy* in 2005 or 2006 (Haley and Ireland 2006; Haley 2006). All previously reported minke whale sightings occurred earlier in the year than the planned operation. Minke whale sightings are unlikely to occur in the survey area during October–December.

Fin Whale (Balaenoptera physalus)

Fin whales are widely distributed in all the world's oceans (Gambell 1985), but typically occur in temperate and polar latitudes and less frequently in the tropics (Reeves et al. 2002). Fin whales feed in northern latitudes during the summer where their prey includes plankton as well as schooling pelagic fish, such as herring, sandlance, and capelin (Jonsgård 1966a,b; Reeves et al. 2002). The North Pacific population summers from the Chukchi Sea in small numbers to California (Gambell 1985), but does not range into the Alaskan Beaufort Sea or waters of the northern Chukchi Sea. Reliable estimates of fin whale abundance in the Northeast Pacific are not available (Allen and Angliss 2011). Provisional estimates of fin whale abundance in the central-eastern and south-eastern Bering Sea are 3368 and 683, respectively (Moore et al. 2002). Zerbini et al. (2006) reported numerous fin whale sightings from Kodiak Island to the central Aleutian Islands.

Fin whales were not recorded during vessel-based or aerial surveys in the Beaufort Sea in 2006–2008 (Savarese et al. 2010; Christie et al. 2010), and were not reported during arctic cruises from the *Healy* in 2005 or 2006 (Haley and Ireland 2006; Haley 2006). Fin whales would be unlikely to occur in the proposed geophysical survey area. The fin whale is listed as endangered under the ESA and by IUCN and is a CITES Appendix I species.

Humpback Whale (Megaptera novaeangliae)

Humpback whales are distributed in major oceans worldwide and their range in the North Pacific extends through the Bering Sea into the southern Chukchi Sea (Allen and Angliss 2011). In general, humpback whales spend winter in tropical and sub-tropical waters where breeding and calving occur, and migrate to higher latitudes for feeding during the summer.

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

Humpback whale sightings in the Bering Sea have been recorded southwest of St. Lawrence Island, in the southeastern Bering Sea, and north of the central Aleutian Islands (Moore et al. 2002; Allen and Angliss 2010). Recently there have been sightings of humpback whales in the Chukchi Sea and a single sighting in the Beaufort Sea (Green et al. 2007). Haley et al. (2010) reported four humpback whales during vessel-based surveys in the Chukchi Sea in 2007 and two sightings in 2008. NMML observers recorded a humpback whale during aerial surveys in the Chukchi Sea in 2009 (COMIDA 2009). Green et al. (2007) reported and photographed a humpback whale cow/calf pair east of Barrow near Smith Bay in 2007. No humpback whales were reported during cruises aboard the Healy in 2005 or 2006 (Haley and Ireland 2006; Haley 2006). Whether the recent humpback whale sightings in the Chukchi and Beaufort seas are related to climate changes in the Arctic in recent years is unknown. Humpback whales would be unlikely to occur in the proposed survey area due to the low numbers that occur in the area and the late fall timing of the survey when humpback whales are typically migrating south to their breeding and calving grounds.

Pinnipeds

Bearded Seal (Erignathus barbatus)

Bearded seals are associated with sea ice and have a circumpolar distribution (Burns 1981b). During the open-water period, bearded seals occur mainly in relatively shallow areas, because they are predominantly benthic feeders (Burns 1981b). They prefer areas of water no deeper than 200 m (Harwood et al. 2005). No reliable estimate of bearded seal abundance is available for the Chukchi and Beaufort seas (Angliss and Allen 2000), however, the Alaska stock of bearded seals is likely greater than 155,000 (Beringia DPS, NMFS 2010a) and may consist of 250,000–300,000 individuals (Popov 1976; Burns 1981b). The Alaska stock of bearded seals, part of the Beringia distinct population segment, has been proposed by NMFS for listing as threatened under the ESA (NMFS 2010a).

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

Seasonal movements of bearded seals appear to be 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 (MacIntyre and Stafford 2011). 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. Bearded seal calling rates in the western Alaskan Beaufort Sea rose steadily beginning in January and peaked in April and July of 2009. Calling rates dropped substantially after July as ice retreated from near the recorder locations, and remained low thereafter (MacIntyre and Stafford 2011). In the Beaufort Sea, bearded seals rarely use coastal haulouts.

In some areas, bearded seals are associated with the ice year-round; however, they usually move shoreward into open water areas when the pack ice retreats to areas with water depths greater than 200 m (Cameron et al. 2009). In the Beaufort Sea, suitable habitat is limited because the continental shelf is 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, although a recent tagging study showed occasional movements of adult bearded seals seaward of the continental shelf (Cameron et al. 2009). WesternGeco conducted marine mammal monitoring during its open-water seismic program in the Alaskan Beaufort Sea from 1996 to 2001. Operations were conducted in nearshore waters, and of a total 454 seals that were identified to species while no guns were operating, 4.4% were bearded seals, 94.1% were ringed seals and 1.5% were spotted seals (Moulton and Lawson 2002).

Haley and Ireland (2006) and Haley (2006) also reported much lower percentages of bearded compared to ringed seals during *Healy* cruises in the Arctic. Haley and Ireland (2006) reported only 7 bearded seal sightings during an arctic cruise from the *Healy* in 2005, and 14 bearded seal sightings were reported during the 2006 *Healy* cruise (Haley 2006).

It is unlikely that many bearded seals would be encountered during the proposed survey because most would typically migrate south with the advancing pack ice into the southern Chukchi and Bering seas. Because some individual seals may remain in the Beaufort and northern Chukchi seas through the winter, it is possible that some bearded seals would be encountered during the survey and the transit south following operations.

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 (Allen and Angliss 2011), but the estimate is most likely between several thousand and several tens of thousands (Rugh et al. 1997). The Alaska stock of spotted seals is not classified as endangered or as a strategic stock by NMFS (Hill and DeMaster 1998). In response to a petition to list spotted seals under the Endangered Species Act (CBD 2008), NMFS concluded that only the southern distinct population segment (DPS), which occurs in Japanese waters, merited listing.

During the summer, spotted seals are found in Alaska from Bristol Bay through western Alaska to the Chukchi and Beaufort seas. The ADF&G placed satellite transmitters on four spotted seals in Kakegaluk Lagoon and estimated that the proportion of seals hauled out was 6.8%. Based on an actual minimum count of 4145 hauled out seals, Allen and Angliss (2011) estimated the Alaskan population at 59,214 animals. The Alaska stock of spotted seals is not classified as endangered, threatened, or as a strategic stock by NMFS (Allen and Angliss 2011).

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

Relatively low numbers of spotted seals are present in the Beaufort Sea. A small number of spotted seal haulouts are (or were) located in the central Beaufort Sea in the deltas of the Colville River and previously the Sagavanirktok River. Historically, these sites supported as many as 400–600 spotted seals, but in the 1990s <20 were seen at any one site (Johnson et al. 1999). A total of 12 spotted seals were positively identified near the source vessel during open-water seismic programs in the central Alaskan Beaufort Sea during the 6 years from 1996 to 2001 (Moulton and Lawson 2002, p. 317).

Numbers seen per year ranged from zero (in 1998 and 2000) to four (in 1999). More recently Green et al. (2007) reported 46 spotted seal sightings during barge operations between West Dock and Cape Simpson. Most sightings occurred from western Harrison Bay to Cape Simpson with only one sighting offshore of the Colville River delta. No spotted seals were identified from the *Healy* during arctic cruises in 2005 or 2006 (Haley and Ireland 2006; Haley 2006).

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

***Ringed Seal* (Phoca hispida)**

Ringed seals have a circumpolar distribution and occur in all seas of the Arctic Ocean (King 1983). They are year-round residents in the Beaufort Sea and ringed seal is the most frequently encountered seal species in the area. No estimate for the size of the Alaska ringed seal stock is currently available (Allen and Angliss 2011). Past ringed seal population estimates in the Bering-Chukchi-Beaufort area ranged from 1–1.5 million (Frost 1985) to 3.3–3.6 million (Frost et al. 1988). Frost and Lowry (1981) estimated 80,000 ringed seals in the Beaufort Sea during summer and 40,000 during winter. More recent estimates based on extrapolation from aerial surveys and on predation estimates for polar bears (Amstrup 1995) suggest an Alaskan Beaufort Sea population of ~326,500 animals. During aerial surveys in 1999 and 2000, Bengtson et al. (2005) reported ringed seal densities 1.62 to 1.91 seals/km^2 in the eastern Chukchi Sea and estimated ringed seal abundance at >250,000 in the their study area in 1999. The Alaska stock, part of the Arctic subspecies of ringed seal, has been proposed for listing as threatened under the ESA (NMFS 2010b).

During late fall and winter, ringed seals occupy shorefast ice and offshore pack ice of the Bering, Chukchi and Beaufort seas (Allen and Angliss 2011). In winter and spring, the highest densities of ringed seals are found on stable shorefast ice. However, in some areas where there is limited fast ice but wide expanses of pack ice, including the Beaufort Sea, Chukchi Sea and Baffin Bay, total numbers of ringed seals on pack ice may exceed those on shorefast ice (Burns 1970; Stirling et al. 1982; Finley et al. 1983). Shorefast ice begins to form in October–November, and persists until May–July, depending on the location. At its maximum extent the shorefast ice extends seaward to about the 20 m isobath, which may be 40 km or more offshore (Stringer et al. 1980).

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

Frost et al. (2004) report ringed seal densities during aerial surveys in the central Alaskan Beaufort Sea during late May and early June 1996–1999 were highest in water depths between 5 and 35 m. Densities were also highest in relatively flat ice and near the fast ice edge, declining both shoreward and seaward of that edge (Frost et al 2004). Seal distribution and density in late May and early June, prior to breakup, are thought to reflect distribution patterns established earlier in the year. Higher abundance could indicate greater prey availability during fall and winter, when seals are actively feeding and when breathing holes are established (Frost et al. 2004). During late fall and winter, a seasonal shift in the ringed seal diet from hyperiid amphipods to arctic cod occurs in the central Beaufort Sea (Lowry et al. 1980; Bluhm and Gradinger 2008). During November–February, arctic cod occur in nearshore areas and spawn (Craig et al. 1984), and this ephemeral prey resource may attract ringed seals.

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

Savarese et al. (2010), consistent with many earlier studies, reported that the ringed seal was the most abundant seal species in the Beaufort Sea during vessel-based surveys in 2006–2008. Haley et al. (2010) also reported that ringed seal was the most abundant seal species during similar vessel-based surveys in the Chukchi Sea those same years.

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

Ribbon Seal (Histriophoca fasciata)

Ribbon seals are found along the pack-ice margin in the southern Bering Sea during late winter and early spring and they move north as the pack ice recedes during late spring to early summer (Burns 1970; Burns et al. 1981a). Little is known about their summer and fall distribution, but Kelly (1988) suggested that they move into the southern Chukchi Sea based on a review of sightings during the summer. During a recent satellite telemetry program sponsored by the NMML, a number of ribbon seals tagged in the Bering Sea in May had moved to the Chukchi Sea by July (NMML 2009). However, ribbon seals appeared to be relatively rare in the northern Chukchi Sea during recent vessel-based surveys in summer and fall of 2006–2008 with only four sightings among 1783 sightings of seals identified to species (Haley et al. 2010). Ribbon seals do not normally occur in the Beaufort Sea; however, three recent ribbon seal sightings were reported during vessel-based activities in the Beaufort Sea in 2008 (Savarese et al. 2010). In response to a petition to list the ribbon seal under the Endangered Species Act (CBD 2007) NMFS concluded that listing of the ribbon seal was not warranted at this time (NMFS 2008). Ribbon seals would be unlikely to occur in the proposed survey area in October–December during the period of the proposed survey.

V. TYPE OF INCIDENTAL TAKE AUTHORIZATION REQUESTED

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

ION Geophysical 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 October–December 2011.

The operations outlined in § I and II have the potential to take marine mammals by harassment. Sounds that may "harass" marine mammals will be generated primarily by the use of airguns during the survey. "Takes" by harassment will potentially result if marine mammals near the activities are exposed to the pulsed sounds generated by the airguns. 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 by some of the marine mammals in the general vicinity of the tracklines of the source vessel may likely occur. Some harassment may occur from non-pulse sounds generated by the icebreaker and seismic vessel traveling through sea ice. Icebreaking will largely occur coincident with seismic activity, and is not expected to contribute significantly to the overall impacts associated with the survey. Further details regarding the potential sound levels and propagation from icebreaking are described below in § VII.

No take by serious injury is anticipated, given the timing and location of the proposed operations, the avoidance ("responsive movement") that cetaceans and some seals exhibit toward an approaching seismic vessel (see § VII, below), and the mitigation measures that are planned (see § XI, "Mitigation Measures"). During the October–December period, there will be no young seal pups in subnivean lairs, so there will be no risk that icebreaking would crush pups or force them into the water prematurely. No lethal takes are expected. However, upon review of the original 2010 IHA application, NMFS specifically requested that estimates of potential "level A takes" based on exposure of seals to ≥190 dB re 1 µPa (rms) and cetaceans to ≥180 dB be included in the application materials.

NMFS has previously stated that the ≥190 dB and ≥180 dB (rms) thresholds are levels at which temporary threshold shift (TTS) may occur in some marine mammals. NMFS has also stated that scientific experts in the field do not consider TTS to result in harm or injury (i.e. to be a "level A take") because no irreversible cell damage is involved (NMFS 2005). In communications regarding ION Geophysical's 2010 application NMFS acknowledged that brief exposure to received levels ≥180 and ≥190 dB (rms) by cetaceans and pinnipeds, respectively, are not likely to cause TTS. The 190 and 180 dB re 1 µPa (rms) criteria were established in the 1990s before there were any specific data on sound levels causing TTS in any marine mammals. They were originally considered to be precautionary "do not exceed" levels above which one could not (at that time) be sure that there would be no injury. In fact, there is no specific empirical evidence as to whether exposure to pulses of airgun sound, even from large arrays of airguns, do or do not cause PTS in any marine mammal (NMFS 2009, Southall et al. 2007).

Nonetheless, NMFS has stated that, because of frequent darkness and the anticipated ice cover, effective mitigation may not be possible during significant portions of the planned seismic survey, and animals could be exposed to the ≥180 dB or ≥190 dB levels for an extended period. In order for animals to be exposed for an extended time they would need to remain close to the vessel and travel in about the same direction and at about the same speed so as to be exposed at close range to numerous seismic impulses, which will occur at ~18 s intervals. In any case, Ion Geophysical has included estimates of the potential number of exposures to sounds ≥180 dB and ≥190 dB in order to move forward with the application process although it expressly disagrees that any "level A takes" will result from its activities.

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 of airgun operations and other sound sources (echo sounder signals and icebreaking) on marine mammals, as called for in Section VII. A more comprehensive review of the relevant background information appears in Appendix C.
- Then we estimate the numbers of marine mammals that might be affected by the proposed activity in the Beaufort and Chukchi seas during October–December 2012. 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.

Summary of Potential Effects of Sounds Generated by Airguns

The airgun array is the only acoustic source planned to be used for data collection purposes during this survey. The effects of sounds from airguns might include one or more of the following: tolerance, masking of natural sounds, behavioral disturbance, and at least in theory, temporary or permanent hearing impairment, or non-auditory physical effects (Richardson et al. 1995a). *In theory* is added because it is unlikely that temporary or especially permanent hearing impairment and non-auditory physical effects would occur.

Tolerance

Numerous studies have shown that pulsed sounds from airguns are often readily detectable in the water at distances of many kilometers. For a summary of the characteristics of airgun pulses, see Appendix C. Numerous studies have shown that marine mammals at distances more than a few kilometers from operating seismic vessels often show no apparent response—see Appendix C. This 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

Introduced underwater sound will, through masking, reduce the effective communication distance of a marine mammal species if the frequency of the source is close to that used as a signal by the marine mammal, and if the anthropogenic sound is present for a significant fraction of the time (Richardson et al.

1995). 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). Bowhead whale calls are frequently detected in the presence of seismic pulses, although the number of calls detected may sometimes be reduced in the presence of airgun pulses (Richardson et al. 1986; Greene et al. 1999; Blackwell et al. 2009a). Bowhead whales in the Beaufort Sea may decrease their call rates in response to seismic operations, although movement out of the area might also have contributed to the lower call detection rate (Blackwell et al. 2009a,b). In contrast, Di Iorio and Clark (2009) found evidence of increased calling by blue whales during operations by a lower-energy seismic source, a sparker. 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 C.

Disturbance Reactions

Disturbance includes a variety of effects, including subtle changes in behavior, more conspicuous changes in activities, and displacement. Based on NMFS (2001, p. 9293), we assume that simple exposure to sound, or brief reactions that do not disrupt behavioral patterns in a potentially significant manner, do not constitute harassment or "taking". By potentially significant, we mean "in a manner that might have deleterious effects to the well-being of individual marine mammals or their populations".

Reactions to sound, if any, depend on species, state of maturity, experience, current activity, reproductive state, time of day, and many other factors. If a marine mammal does react briefly to an underwater sound by changing its behavior or moving a small distance, the impacts of the change are unlikely to be significant to the individual, let alone the stock or the species as a whole. However, if a sound source displaces marine mammals from an important feeding or breeding area for a prolonged period, impacts on the animals could be significant. Given the many uncertainties in predicting the quantity and types of impacts of noise on marine mammals, it is common practice to estimate how many mammals were present within a particular distance of industrial activities, or exposed to a particular level of industrial sound. That likely overestimates the numbers of marine mammals that are affected in some biologically-important manner.

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

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

Studies of gray, bowhead, and humpback whales have determined that received levels of pulses in the 160–170 dB re 1 μPa (rms) range seem to cause obvious avoidance behavior in a substantial fraction of the animals exposed. In many areas, seismic pulses from large arrays of airguns diminish to those levels at distances ranging from 4.5 to 14.5 km from the source. A substantial proportion of the baleen whales within those distances may show avoidance or other strong disturbance reactions to the airgun array. Subtle behavioral changes sometimes become evident at somewhat lower received levels, and recent studies reviewed in Appendix C 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 (12–19 mi) from a medium-sized airgun source (Miller et al. 1999; Richardson et al. 1999; see Appendix C). However, more recent research on bowhead whales (Miller et al. 2005; Lyons et al. 2009; Christie et al. 2010) corroborates earlier evidence that, during the summer feeding season, bowheads are not as sensitive to seismic sources. In summer, bowheads typically begin to show avoidance reactions at a received level of about 160–170 dB re 1 μPa (rms) (Richardson et al. 1986; Ljungblad et al. 1988; Miller et al. 2005).

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. These findings were generally consistent with the results of studies conducted on larger numbers of gray whales migrating off California (Malme et al. 1984; Malme and Miles 1985) and western Pacific gray whales feeding off Sakhalin, Russia (Würsig et al. 1999; Gailey et al. 2007; Johnson et al. 2007; Yazvenko et al. 2007a,b), along with a few data on gray whales off British Columbia (Bain and Williams 2006).

Data on short-term reactions (or lack of reactions) of cetaceans to impulsive noises do not necessarily provide information about long-term effects. It is not known whether impulsive noises affect reproductive rate or distribution and habitat use in subsequent days or years. However, gray whales continued to migrate annually along the west coast of North America despite intermittent seismic exploration and much ship traffic in that area for decades (Appendix A *in* Malme et al. 1984). Bowhead whales continued to travel to the eastern Beaufort Sea each summer despite seismic exploration in their summer and autumn range for many years (Richardson et al. 1987). Populations of both gray whales and bowhead whales grew substantially during this time.

This seismic survey is not expected to have a significant impact on gray whales because it is unlikely that they will be present in the survey area in October–December. Most bowhead whales will have migrated south into the southern Chukchi and Bering seas by this time as well. The survey was carefully designed (both spatially and temporally) to ensure that whale density in areas of seismic activity will be minimal; therefore significant effects on baleen whales are not expected. Furthermore, in the event that a few individuals are approached by the operating seismic vessel, their tendency to avoid close approach by seismic vessels will prevent any possibility of auditory or other physiological effects.

Toothed Whales.— Few systematic data are 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 more detail) in Appendix C have been reported for toothed whales. However, there has been systematic work on sperm whales (for review, see Appendix C), and there is an increasing amount of information about responses of various small odontocetes to seismic surveys based on monitoring studies (e.g., Stone 2003; Smultea et al. 2004; Moulton and Miller 2005; see Appendix C).

Seismic operators and marine mammal observers 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, 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; Appendix C).

The beluga may be a species that (at least at times) shows long-distance avoidance of seismic vessels. Aerial surveys during seismic operations in the southeastern Beaufort Sea recorded much lower sighting rates of beluga whales within 10–20 km of an active seismic vessel. These results were consistent with the low number of beluga sightings reported by observers aboard the seismic vessel, suggesting that some belugas might be avoiding the seismic operations at distances of 10–20 km (Miller et al. 2005).

Captive bottlenose dolphins and (of more 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. 2002, 2005). However, the animals tolerated high received levels of sound (pk–pk level >200 dB re 1 µPa) before exhibiting aversive behaviors. The reactions of belugas to the ION survey would likely be similar to those of free-ranging belugas exposed to airgun sound (Miller et al. 2005) rather than to those of captive belugas exposed to a different type of strong transient sound (Finneran et al. 2000, 2002).

Odontocete reactions to large arrays of airguns are variable and, at least for delphinids, seem to be confined to a smaller radius than has been observed for mysticetes (Apppendix C). A ≥170 dB disturbance criterion (rather than ≥160 dB) is considered appropriate for delphinids (and pinnipeds), which tend to be less responsive than other cetaceans. However, based on the limited existing evidence, belugas should not be grouped with delphinids in the “less responsive” category. The beluga is the only toothed whale species likely to be encountered during the proposed survey.

Pinnipeds.—Pinnipeds are not likely to show a strong avoidance reaction to the 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 C. Ringed seals frequently do not avoid the area within a few hundred meters of operating airgun arrays (Harris et al. 2001; Moulton and Lawson 2002; Miller et al. 2005). However, initial telemetry work suggests that avoidance and other behavioral reactions by two other species of seals 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). Additionally, Reiser et al. (2009) reported a tendency for localized avoidance of areas immediately around the seismic source vessel along with coincident increased sighting rates at support vessels operating 1–2 km away. Reactions of the species occurring in the proposed study area are expected to be limited to localized avoidance of the seismic activity (and vessels) by some individuals, with no long-term effects on pinniped individuals or populations resulting from behavioral reactions.

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 C 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 ; Scholik-Schlomer in press). New science-based noise exposure criteria were proposed by a group of experts in the field, based on an extensive review and synthesis of available data on the effect of noise on marine mammals (Southall et al., 2007) and this review seems to confirm that the current 180 dB and 190 dB are cautionary.

Several aspects of the planned monitoring and mitigation measures for this project are designed to detect marine mammals occurring near the airguns 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 proposed study area. It is unlikely that any effects of these types would occur during the proposed project given the brief duration of exposure of any given mammal. 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. At least in terrestrial mammals, TTS can last from minutes or hours to (in cases of strong TTS) days. For sound exposures at or somewhat above the TTS threshold, hearing sensitivity in both terrestrial and marine mammals recovers rapidly after exposure to the noise ends. Few data on sound levels and durations necessary to elicit mild TTS have been obtained for marine mammals, and none of the published data concern TTS elicited by exposure to multiple impulses of sound. [There are, however, recent data on TTS in dolphins caused by multiple pulses of sonar sound—Mooney et al. (2009).]

The distinction between TTS and PTS is not absolute. Although mild TTS is fully reversible and is not considered to be injury, exposure to considerably higher levels of sound causes more "robust" TTS, involving a more pronounced temporary impairment of sensitivity that takes longer to recover. There are very few data on recovery of marine mammals from substantial degrees of TTS, but in terrestrial mammals there is evidence that "robust" TTS may not be fully recoverable, i.e., TTS can grade into PTS (Le Prell in press).

The received energy level of a single seismic pulse that caused the onset of mild TTS in the beluga, as measured without frequency weighting, was ~186 dB re 1 $\mu Pa^2 \cdot s$ or 186 dB SEL (Finneran et al. 2002).[1] The rms level of an airgun pulse (in dB re 1 μPa measured over the duration of the pulse) is typically 10–15 dB higher than the SEL for the same pulse when received within a few kilometers of the airguns. Thus, a single airgun pulse might need to have a received level of ~196–201 dB re 1 μPa (rms) in order to produce brief, mild TTS. Exposure to several strong seismic pulses that each has a flat-weighted received level near 190 dB (rms) (175–180 dB SEL) could result in cumulative exposure of ~186 dB SEL (flat-weighted) or ~183 dB SEL (M_{mf}-weighted), and thus slight TTS in a small odontocete. That assumes that the TTS threshold upon exposure to multiple pulses is (to a first approximation) a function of the total received pulse energy, without allowance for any recovery between pulses.

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 size of the source, and the strong likelihood that baleen whales (especially migrating bowheads) 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, 2005; Ketten et al. 2001; cf. Au et al. 2000). For harbor seal, which is closely related to the ringed seal, TTS onset apparently occurs at somewhat lower received energy levels than for odontocetes [see Appendix C].

A marine mammal within a radius of ≤100 m (≤109 yd) 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. (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:

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

- "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.
- Even in the case of the rare cetacean that fails to avoid close approach of an operating airgun array, 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.
- With a large array of airguns, TTS would be most likely in any odontocetes that bow-ride or in any odontocetes or pinnipeds that linger near the airguns. For the proposed survey, the anticipated 180-dB and 190-dB safety zones in shallow water are expected to extend ~2850 and 670 m, respectively, from the airgun array. However, these safety zones are expected to be much shorter distances in waters >100 m deep, where two thirds of the survey will take place. Given these distances, the proposed survey could result in effects to bow-riding species; however, no species that occur within the project area are expected to bow-ride.
- There is a possibility that a small number of seals (which often show little or no avoidance of approaching seismic vessels) could occur close to the airguns and that they might incur TTS if no mitigation action (shutdown) were taken. The ringed seal is the only pinniped species expected to be present in the survey area in October–December in significant numbers, and it is possible that bearded seals may be present as well.

NMFS (1995, 2000) concluded that cetaceans and pinnipeds should not be exposed to pulsed underwater noise at received levels exceeding 180 and 190 dB re 1 μPa (rms), respectively. The 180 and 190 dB (rms) distances for the airguns operated by ION are likely to vary with water depth. Depending on water depth, the maximum 190 and 180 dB (rms) radii were modeled by JASCO (Zykov et al. 2010) to be 180–600 m and 580–2850 m, respectively. Precautionary shut down distances calculated using the maxima of modeled sound radii (as opposed to the 95% upper confidence limits of the modeled radii) are proposed to be used until these radii can be measured empirically. The 180 and 190 dB (rms) safety radii will be revised when results are available from in-field measurements of the airgun array sounds to be obtained at the start to the seismic survey (see §XIII). Furthermore, established 190 and 180 dB (rms) criteria are not considered to be the levels above which TTS might occur. Rather, they are the received levels above which, in the view of a panel of bioacoustics specialists convened by NMFS before TTS measurements for marine mammals started to become available, one could not be certain that there would be no injurious effects, auditory or otherwise, to marine mammals.

As summarized above, data that are now available suggest that TTS in cetaceans is unlikely to occur unless odontocetes (and by implication mysticetes) are exposed to airgun pulses stronger than 180 dB re 1 μPa (rms). Since Arctic cetaceans show avoidance at received levels ≤180 dB, and no bow-riding species occur in the study area, it is unlikely such exposures will occur.

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

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 (Southall et al. 2007; Le Prell in press). PTS might occur at a received sound level at least several decibels above that inducing mild TTS if the animal were exposed to the strong sound pulses with very rapid rise time—see Appendix C.

It is unlikely that cetaceans could receive sounds strong enough (and over a sufficient duration) to cause permanent hearing impairment during a project employing the airgun sources planned here. In the proposed project, cetaceans are unlikely to be exposed to received levels of seismic pulses strong enough to cause more than slight TTS. Given the higher level of sound necessary to cause PTS, it is even less likely that PTS could occur. Baleen whales, and apparently belugas as well, 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 help to minimize the already-minimal probability of exposure of cetaceans to sounds strong enough to induce PTS.

Based on data from terrestrial mammals, a precautionary assumption is that the PTS threshold for impulse sounds (such as airgun pulses as received close to the source) is at least 6 dB higher than the TTS threshold on a peak-pressure basis, and probably >6 dB higher (Southall et al. 2007). The low-to-moderate levels of TTS that have been induced in captive odontocetes and pinnipeds during controlled studies of TTS have been confirmed to be temporary, with no measurable residual PTS (Kastak et al. 1999; Schlundt et al. 2000; Finneran et al. 2002, 2005; Nachtigall et al. 2003, 2004). Southall et al. (2007) estimated that the PTS threshold could be a cumulative M_{pw}-weighted SEL of ~186 dB re 1 $\mu Pa^2 \cdot s$ in the case of a harbor seal exposed to impulse sound. Thus, PTS might be expected upon exposure of pinnipeds to either SEL ≥186 dB re 1 $\mu Pa^2 \cdot s$ or peak pressure ≥218 dB re 1 µPa (Southall et al. 2007).

Estimates of potential “level A takes” based on exposures of marine mammals to sounds ≥180 dB and ≥190 dB included in this application were specifically requested by NMFS. However, it is ION’s belief that the materials in this section support the fact that no marine mammals will be harmed by the activities proposed in this survey and there will be no “level A takes.”

Non-auditory Physiological Effects.— Non-auditory physiological effects or injuries that theoretically might occur in marine mammals exposed to strong underwater sound include stress, neurological effects, bubble formation, and other types of organ or tissue damage. However, studies examining such effects are very limited. If any such effects do occur, they probably would be limited to unusual situations when animals might be exposed at close range for unusually long periods. It is doubtful that any single marine mammal would be exposed to strong seismic sounds for sufficiently long that significant physiological stress would develop. That is especially so in the case of the proposed project where the airgun configuration focuses most energy downward, the ship is moving at 4–5 knots, and for the most part, the tracklines will not “double back” through the same area.

Until recently, it was assumed that diving marine mammals are not subject to the bends or air embolism. This possibility was first explored at a workshop (Gentry [ed.] 2002) held to discuss whether the stranding of beaked whales in the Bahamas in 2000 (Balcomb and Claridge 2001; NOAA and USN 2001) might have been related to bubble formation in tissues caused by exposure to noise from naval sonar. However, the opinions were inconclusive. Jepson et al. (2003) first suggested a possible link between mid-frequency sonar activity and acute and chronic tissue damage that results from the formation *in vivo* of gas bubbles, based on the beaked whale stranding in the Canary Islands in 2002 during naval exercises. Fernández et al. (2005a) showed those beaked whales did indeed have gas bubble-associated lesions as well as fat embolisms. Fernández et al. (2005b) also found evidence of fat embolism in three beaked whales that stranded 100 km (62 mi) 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 has been in beaked whales, which do not occur in the proposed survey 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 (Appendix B, Section 6.3 provides additional details). However, the association of mass strandings of beaked whales with naval exercises and, in one case, a 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.

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 (Balcomb and Claridge 2001; 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. As noted above, beaked whales appear to be the most susceptible to stranding in connection with pulsed sounds; however, no beaked whales are found within the proposed survey area.

Possible Effects of Echo Sounder Signals

Both the *Geo Arctic* and the *Polar Prince* each operate one echosounder. Both vessels operate the instruments during all vessel operations to provide water depth information to the crew as a routine safety measure. The *Geo Arctic's* echosounder (i.e., fathometer) is a Simrad EA600. The echo sounder on the *Polar Prince* is an ELAC LAZ-72. These units emit sounds in a conical beam (10°–20°) downward from a transducer mounted on the bottom of the vessel. Source levels of navigational echo sounders of this type are typically in the 180–200 dB re 1 µPA-m (Richardson et al. 1995a).

Sounds from echo sounders are typically very short pulses whose characteristics vary depending on water depth. Most of the energy in the sound pulses emitted by echo sounders is at high frequencies. The downward-facing single beam is narrow, and any 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 various echosounders, even at close range, are unlikely to be subjected to repeated pulses because of the narrow beam, and will receive only limited amounts of pulse energy because of the short pulses. The animal would have to pass the transducer on the bottom of the vessel at close range and continue swimming at the same speed and direction as the vessel in order to be subjected to repeated pulses that could cause TTS.

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

Masking

The echo sounders produce sounds within the frequency range used by odontocetes and within the frequency range heard by pinnipeds and potentially baleen whales; however communication for these species will not be masked appreciably given the low duty cycle and the brief period when an individual mammal is likely to be within the 10°–20° downward directed conical beam.

Behavioral Responses

Captive bottlenose dolphins and a beluga whale exhibited changes in behavior when exposed to 1 s pulsed sounds at lower frequencies (3, 10 and 20 kHz) than those expected to be emitted by the echo sounders to be used by ION. Behavioral changes typically involved what appeared to be deliberate attempts to avoid the sound exposure (Schlundt et al. 2000; Finneran et al. 2002; Finneran and Schlundt 2004). The relevance of those data to free-ranging odontocetes is uncertain, and in any case, the test sounds were quite different in either duration or bandwidth as compared with those from echo sounders.

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

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 proposed situation. Pulse durations from the Navy sonars were much longer than those of the echo sounders to be used during the proposed study, and a given mammal would have received many horizontally–directed pulses while in the vicinity of the naval sonars. During ION's operations, the individual pulses will be very short, and a given mammal would not receive many of the downward-directed pulses as the vessel passes by.

NMFS (2001) has concluded that momentary behavioral reactions "do not rise to the level of taking". Thus, brief exposure of cetaceans or pinnipeds to small numbers of signals from the echo sounder would not result in a "take" by harassment.

Hearing Impairment and Other Physical Effects

Given recent stranding events that have been associated with the operation of naval sonar, there is concern that mid-frequency sonar sounds can cause serious impacts to marine mammals (see above). However, the echo sounders proposed for use by ION are quite different from sonars used for navy operations. Pulse duration of the echo sounder is very short relative to the naval sonars. Also, at any given location, an individual cetacean or pinniped would be in the beam of the echo sounder for much less time given the generally downward orientation of the beam and its narrow beamwidth. (Navy sonars often use near-horizontally-directed sound.) Those factors would all reduce the sound energy received from the echo sounder relative to that from the sonars used by the Navy.

Possible Effects of Icebreaking Activities

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

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

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

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

Beluga whales are expected to avoid icebreaking vessels at distances of ~10 km. The impacts of icebreaking associated with the seismic program on the behavior of belugas are expected to be temporary, lasting only as long as the activity is on-going in the vicinity, and would not have any effect on the beluga population. Also, as noted above, belugas are expected to be scarce within the operating area during October–December, so any disturbance effects are expected to be infrequent.

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

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

Bowhead whales are expected to avoid vessels that are underway, especially icebreakers that are breaking ice and producing additional sound during that activity. However, during the planned project, icebreaking would affect the behavior of bowheads only if bowheads are still in the study area during the early part of the seismic project and if there is much ice cover at that time. Most bowheads will likely have passed through the survey area prior to the start of survey activities. The effects of icebreaking activities on bowhead whales are expected to be minor and short-term.

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

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

Ringed seals and any bearded seals encountered in October–December during the planned project would not include any newborn pups. At that time of year, there would be no concern about crushing of ringed seal pups in lairs, or about seal pups being forced into the water at an early age.

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

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 and anticipated behavior of the animals will minimize the possibility of injurious takes. (However, as noted earlier and in Appendix C, there is no specific information demonstrating that injurious "takes" would occur even in the absence of the planned mitigation measures.) The sections below describe methods used to estimate "take by harassment" and present estimates of the numbers of marine mammals that might be affected during the proposed seismic study in the U.S. Beaufort Sea. The estimates are based on data obtained during marine mammal surveys in the Beaufort Sea and on estimates of the sizes of the areas where effects could potentially occur. In some cases, these estimates were made from data collected from regions and habitats that differed from the proposed project area. Adjustments to reported population or density estimates were made on a case by case basis to account for differences between the source data and the available information on the seasonal distribution and abundance of the species in the project area. This section provides estimates of the number of potential "exposures" to sound levels ≥160 dB re 1 µPa (rms) and continuous (or non-pulse) sound levels ≥120 dB (rms) from icebreaking. At the direction of NMFS, this section also includes estimates of exposures to ≥180 dB (rms) for cetaceans and ≥190 dB (rms) for seals.

Although several systematic surveys of marine mammals have been conducted in the southern Beaufort Sea during spring and summer, few data (systematic or otherwise) are available on the distribution and numbers of marine mammals during the late autumn period of this survey, particularly in the northern Beaufort Sea. The main sources of distributional and numerical data used in deriving the estimates are described in the next subsection. There is some uncertainty about how representative those data are and the assumptions used below to estimate the potential “take by harassment”. However, the approach used here is accepted by NMFS as the best available at this time. The following estimates are based on a consideration of the number of marine mammals that might be disturbed appreciably by ~7175 line kilometers of seismic surveys across the Beaufort Sea and, to a lesser extent, the northern Chukchi Sea.

Marine Mammal Density Estimates

This section describes the estimated densities of marine mammals that may occur in the survey area. The area of water that may be ensonified to various levels is described below in the section *Potential Number of “Takes by Harassment.”* There is no evidence that avoidance at received sound levels of ≥160 dB would have significant effects on individual animals or that the subtle changes in behavior or movements would “rise to the level of taking” according to guidance by the NMFS (NMFS 2001). Any changes in behavior caused by sounds ≥160 dB re 1 μPa (rms) from seismic, or the 120 dB (rms) level from icebreaking, would likely fall within the normal range of variation in behavior that would occur in the absence of this survey.

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

Separate densities were calculated for habitats specific to cetaceans and pinnipeds. For cetaceans, densities were estimated for areas of water depth <200 m, 200–1000 m, and >1000 m, which approximately correspond to the continental shelf, the continental slope, and the abyssal plain, respectively. Separate densities of both cetacean and pinnipeds were also estimated for the east and west survey areas within each water depth category. However, pinniped densities in the west survey area and <200 m water depth category were further sub-divided into <35 m and 35–200 m depth categories. This was done because the west survey area is not expected to be surveyed until November–December, and based on historic sea ice data (NOAA National Ice Center, available online at www.natice.noaa.gov), it is expected that substantial amounts of sea ice, including shorefast ice, will be present in the west survey area at that time. Past studies have found that seal densities in ice-covered areas of the Beaufort Sea are different where water depths are <35 m and >35 m (Moulton et al. 2002; Frost et al. 2004); therefore, densities were calculated separately for these water depths. The north-eastern Chukchi Sea is composed of mostly continental shelf waters between 30 m and 200 m in depth, so only a single density estimate for each marine mammal species was used in that area. Since most marine mammals will be continuing their southerly migration in November and early December, the same density estimates for continental shelf waters in the west survey area of the Beaufort Sea were used in the Chukchi Sea.

To provide some allowance for uncertainties, “maximum estimates” as well as “best (average) estimates” of the numbers potentially affected were calculated. For a few marine mammal species, several density estimates were available, and in those cases, the mean and maximum estimates were calculated from the survey data. When the seismic survey area is on the edge of the range of a species at this time of year, we assumed that the average density along the seismic trackline will be 10 % (0.10×) the density determined from available survey data within the main range. Density estimates for the Chukchi during the period of November–December were taken from the west survey density estimates at the appropriate depth.

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

Cetaceans

Beluga density estimates were calculated based on aerial survey data collected in October in the eastern Alaskan Beaufort Sea by the NMML (as part of the BWASP program funded by BOEMRE) in 2007–2010. They reported 31 sightings of 66 individual whales during 1597 km of on-transect effort over waters 200–2000 m deep (Ferguson, M. pers comm.). An $f(0)$ value of 2.326 was applied and it was calculated using beluga whale sightings data collected in the Canadian Beaufort Sea (Innes et al. 2002). A $g(0)$ value of 0.419 was used that represents a combination of $g_a(0) = 0.55$ (Innes et al. 2002) and $g_d(0) = 0.762$ (Harwood et al. 1996). The resulting density estimate (0.1169 individuals/km^2; Table 2) was applied to areas of 200–1000 m. There were 3 sightings of 4 individual beluga whales during 7482 km of on-transect effort over waters 0–200 m deep during this same time period. Using the same $f(0)$ and $g(0)$ values from above, the resulting density estimate for continental shelf waters (0–200 m deep) is 0.0015 individuals/km^2 (Table 2). The density estimate for waters >1000 m deep was estimated as 40% of the 200–1000 m density based on the relative number of sightings in the two water depth categories. For all water depth and survey area categories, the maximum beluga density estimates represent the mean estimates multiplied by four to allow for chance encounters with unexpected large groups of animals or overall higher densities than expected.

Beluga density estimates for the west survey area, which is planned to be surveyed beginning in November, represent the east survey area estimates multiplied by 0.10 because the Beaufort Sea and north-eastern Chukchi Sea is believed to be at the edge of the species’ range in November–December. Belugas typically migrate into the Bering Sea for the winter (Allen and Angliss 2011) and are not expected to be present in the study area in high numbers in November–December. Satellite tagging data support this and indicate belugas migrate out of the Beaufort Sea in the October–November period (Suydam et al. 2005).

Bowhead whale density estimates were calculated based on aerial survey data collected in the Beaufort Sea as part of the BWASP program funded by BOEMRE (now BOEM). The average density estimate was based on surveys in October 2007–2010 and the maximum density estimate was based on surveys conducted in October 1997–2004. The earlier data were used to calculate the maximum estimate because they include some years of unusually high numbers of bowhead sightings in the western Alaskan Beaufort Sea at that time of year. The 2007–2010 data included 25 on-transect sightings collected during

7,482 km of effort over waters 0–200 m deep in the eastern Alaskan Beaufort Sea. The 1997–2004 data included 147 on-transect sightings of 472 individual whales collected during 20,340 km of effort over waters 0–200 m deep in the eastern Alaskan Beaufort Sea. An $f(0)$ correction factor of 2.33 used in the density calculation was the result of a weighted average of the $f(0)$ values applied to each of the MMS flights (Richardson and Thomson 2002). The multiplication of $g_a(0) = 0.144$ and $g_d(0) = 0.505$ correction factors reported in Richardson and Thomson (2002) gave the $g(0)$ value of 0.0727 used in the density calculation. The resulting density estimates (0.0942 whales/km^2 and 0.3719 whales/km^2) represent the average and maximum densities, respectively for October for areas of <200 m water depth, and are referred to below as the reference density for bowhead whales.

Because bowhead whale density is typically higher in continental shelf waters of the Beaufort Sea in early October, the survey has been planned to start in the eastern U.S. Beaufort Sea in waters deeper than 1000 m (ice conditions permitting), where bowhead density is expected to be much lower. Survey activity in shallower waters will proceed from east to west starting later in October as bowhead whales migrate west out of the Beaufort Sea. The nearshore lines in the east survey area will be surveyed during late October. Bowhead density in the east survey area in waters <200 m deep was estimated by taking ten percent of the reference density above (Table 2). This adjustment was based on data from Miller et al. (2002) that showed a ~90% decrease in bowhead whale abundance in the eastern Alaskan Beaufort Sea from early to late October.

Bowhead whale densities in intermediate (200–1000 m) and deep (>1000 m) water depths in the east survey area are expected to be quite low. Ninety-seven percent of sightings recorded by MMS aerial surveys 1997–2004 occurred in areas of water depth <200 m (Treacy 1998, 2000, 2002a,b; Monnett and Treacy 2005). Therefore, density estimates for areas of water depth 200–1000 m were estimated to be ~3% of the values for areas with depth <200 m. This is further supported by Mate et al. (2000), who found that 87% of locations from satellite-tagged bowhead whales occurred in areas of water depth <100 m. In areas with water depth >1000 m, ~4225 km of aerial survey effort occurred during October 1997–2004; however no bowhead sightings were recorded. The effort occurred over eight years, so it is unlikely that this result would have been influenced by ice cover or another single environmental variable that might have affected whale distribution in a given year. Therefore, a minimal density estimate (0.0001 whales/km^2) was used for areas with water depth >1000 m.

Several sources were used to estimate bowhead whale density in the west survey area, including the north-eastern Chukchi Sea, which is expected to be surveyed beginning in late October or early November. Mate et al. (2000) found that satellite-tagged bowhead whales in the Beaufort Sea travelled at an average rate of 88 km per day. At that rate, an individual whale could travel across the extent of the east survey area in four days and across the entire east-west extent of the survey area in ten days, if it did not stop to feed during its migration, as bowhead whales have been observed to do earlier in the year (Christie et al. 2010). Also, Miller et al. (2002) presented a 10-day moving average of bowhead whale abundance in the eastern Beaufort Sea using data from 1979–2000 that showed a decrease of ~90% from early to late October. Based on these data, it is expected that almost all whales that had been in the east survey area during early October would likely have migrated beyond the survey areas by November–December. In addition, kernel density estimates and animal tracklines generated from satellite-tagged bowhead whales, along with acoustic monitoring data, suggest that few bowhead whales are present in the proposed survey area in November (near Point Barrow), and no whales were present in December (ADFG 2010; Moore et al. 2010). Therefore, density estimates for the <200 m and 200–1000 m water depth categories in the west survey area were estimated to be one tenth of those estimates for the east survey area. Minimal density estimates (0.0001 whales/km^2) were used for areas of water depth >1000 m.

TABLE 2. Expected densities of cetaceans in the Arctic Ocean in October–December by water depth and survey area. Species listed as endangered are in italics.

	<200 m		200–1000 m		>1000 m	
Species	**Average density (#/km^2)**	**Maximum density (#/km^2)**	**Average density (#/km^2)**	**Maximum density (#/km^2)**	**Average density (#/km^2)**	**Maximum density (#/km^2)**
Beaufort East survey area						
Odontocetes						
Beluga	0.0015	0.0060	0.1169	0.4676	0.0468	0.1870
Harbor porpoise	0.0001	0.0004	0.0001	0.0004	0.0001	0.0004
Mysticetes						
Bowhead whale	0.0094	0.0372	0.0028	0.0112	0.0001	0.0004
Gray whale	0.0001	0.0004	0.0001	0.0004	0.0001	0.0004
Minke whale	0.0001	0.0004	0.0001	0.0004	0.0001	0.0004
Humpback whale	0.0001	0.0004	0.0001	0.0004	0.0001	0.0004
Beaufort West survey area						
Odontocetes						
Beluga	0.0002	0.0006	0.0117	0.0468	0.0047	0.0187
Harbor porpoise	0.0001	0.0004	0.0001	0.0004	0.0001	0.0004
Mysticetes						
Bowhead whale	0.0009	0.0037	0.0003	0.0011	0.0001	0.0004
Gray whale	0.0001	0.0004	0.0001	0.0004	0.0001	0.0004
Minke whale	0.0001	0.0004	0.0001	0.0004	0.0001	0.0004
Humpback whale	0.0001	0.0004	0.0001	0.0004	0.0001	0.0004
Chukchi survey area						
Odontocetes						
Beluga	0.0002	0.0006	-	-	-	-
Harbor porpoise	0.0001	0.0004	-	-	-	-
Mysticetes						
Bowhead whale	0.0009	0.0037	-	-	-	-
Gray whale	0.0001	0.0004	-	-	-	-
Minke whale	0.0001	0.0004	-	-	-	-
Humpback whale	0.0001	0.0004	-	-	-	-

Other cetacean species are not expected to be present in the area at the time of the planned survey. These species, including humpback whale, fin whale, minke whale, and harbor porpoise, typically migrate during autumn and are expected to be south of the proposed survey area by the October–December period. Gray whales have been detected near Pt. Barrow during the period of the proposed project, and even through throughout the winter (Moore et al. 2006, Stafford et al. 2007). Authorization for minimal takes of other cetacean species that are known to occur in the Beaufort Sea during the summer have been requested in case of a chance encounter of a few remaining individuals.

Pinnipeds

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

Ringed seal density for the east survey area for waters <1000 m deep was estimated using vessel-based data collected in the Beaufort Sea during autumn (Sep–Oct) 2006–2008 and reported by Savarese et al. (2010; Table 3). Correction factors for sightability and availability were used when the authors calculated the estimates, so no further adjustments were required. For the east survey area for waters >1000 m deep, few data on seal distribution are available. Harwood et al. (2005) recorded a ringed seal sighting in the Beaufort Sea in an area where water depth was >1000 m in September–October 2002 during an oceanographic cruise. It is therefore possible that ringed seals would occur in those areas, and their presence would likely be associated with ephemeral prey resources. If a relatively warm surface eddy formed that concentrated prey in offshore areas at depths that would be possible for ringed seals to access, it is possible that seals would be attracted to it. A warm eddy was found in the northern Beaufort Sea in October 2002 in an area where water depth was >1000 m (Crawford 2010), so it is possible that such an oceanographic feature might develop again and attract seals offshore. However, it is unclear whether such a feature would attract many seals, especially since the marine mammal observers present on the ship in 2002 did not observe very many seals associated with the offshore eddy. In the absence of standardized survey data from deep-water areas, but with available data suggesting densities are likely to be quite low, minimal density estimates (0.0001 seals/km^2) were used in areas where water depth is >1000 m. For all water depth categories in the east survey area, the maximum ringed seal density was assumed to be the mean estimate multiplied by four to allow for chance encounters with unexpected large groups of animals or overall higher densities than expected.

Habitat zones and associated densities were defined differently in the west survey area, which will be surveyed in November–December, because more ice is expected to be encountered at that time than in October (NOAA National Ice Center: www.natice.noaa.gov). The density estimates for the west survey area were calculated using aerial survey data collected by Frost et al. (2004) in the Alaskan Beaufort Sea during the spring. A $g(0)$ correction factor of 0.60 from tagging data reported by Bengtson et al. (2005) was used to adjust all density estimates from Frost et al. (2004) described below. Seal distribution and density in spring, prior to breakup, are thought to reflect distribution patterns established earlier in the year (i.e., during the winter months; Frost et al. 2004). Density estimates were highest (1.00–1.33 seals/km^2) in areas of water depth 3–35 m, and decreased (0–0.77 seals/km^2) in water >35 m deep. The mean density estimate used for areas with water depth <35 m (Table 4) was estimated using an average of the pack ice estimates modeled by Frost et al. (2004). The maximum estimate for the same area is the maximum observed density for areas of water depth 3–35 m in Frost et al. (2004). The mean density estimate used for areas with 35–200 m water depth is the modeled value for water depth >35 m from Frost et al. (2004). The maximum estimate is the maximum observed density for areas with >35 m water depth in Frost et al. (2004). Because ringed seal density tends to decrease with increasing water depth (Moulton et al. 2002; Frost et al. 2004), ringed seal density was estimated to be minimal in areas of >200 m water depth.

In the Chukchi Sea, ringed seal densities were taken from offshore aerial surveys of the pack ice zone conducted in spring 1999 and 2000 (Bengtson et al. 2005). The average density from those two years (weighted by survey effort) was 0.4892 seals/km^2. This value served as the average density while the highest density from the two years, (0.8100 seals/km^2 in 1999) was used as the maximum density.

TABLE 3. Expected densities of pinnipeds in the east survey area of the U.S. Beaufort Sea in October.

	Beaufort East Survey Area					
	<200 m		**200–1000 m**		**>1000 m**	
Species	**Average density (#/km^2)**	**Maximum density (#/km^2)**	**Average density (#/km^2)**	**Maximum density (#/km^2)**	**Average density (#/km^2)**	**Maximum density (#/km^2)**
Ringed seal	0.0840	0.3360	0.0840	0.3360	0.0004	0.0016
Bearded seal	0.0004	0.0016	0.0004	0.0016	0.0004	0.0016
Spotted seal	0.0001	0.0004	0.0001	0.0004	0.0001	0.0004
Ribbon seal	0.0001	0.0004	0.0001	0.0004	0.0001	0.0004

TABLE 4. Expected densities of pinnipeds in the Beaufort West and Chukchi survey areas of the Arctic Ocean in November–December.

	Beaufort West and Chukchi survey areas					
	<35 m		**35–200 m**		**>200 m**	
Species	**Average density (#/km^2)**	**Maximum density (#/km^2)**	**Average density (#/km^2)**	**Maximum density (#/km^2)**	**Average density (#/km^2)**	**Maximum density (#/km^2)**
Beaufort West						
Ringed seal	1.9375	2.2167	1.0000	1.2833	0.0004	0.0016
Bearded seal	0.0004	0.0016	0.0004	0.0016	0.0004	0.0016
Spotted seal	0.0001	0.0004	0.0001	0.0004	0.0001	0.0004
Ribbon seal	0.0001	0.0004	0.0001	0.0004	0.0001	0.0004
Chukchi						
Ringed seal	-	-	0.4892	0.8100	-	-
Bearded seal	-	-	0.0004	0.0016	-	-
Spotted seal	-	-	0.0001	0.0004	-	-
Ribbon seal	-	-	0.0001	0.0004	-	-

Other seal species are not expected to be present in the study area during the period of this survey. Bearded and spotted seals would be present in the area during summer, and possibly ribbon seals as well, but they generally migrate into the southern Chukchi and Bering seas during fall (Allen and Angliss 2011). Few satellite-tagging studies have been conducted on these species in the Beaufort Sea, winter surveys have not been conducted, and a few bearded seals have been reported over the continental shelf in spring prior to general breakup. However, three bearded seals tracked in 2009 moved south into the Bering Sea along the continental shelf by November (Cameron and Boveng 2009). It is possible that some individuals, bearded seals in particular, may be present in the survey area. In the absence of better information from the published literature or other sources that would indicate significant numbers of any of these species might be present, minimal density estimates were used for all areas and water depth categories for these species, with the estimates for bearded seals assumed to be slightly higher than those for spotted and ribbon seals (Tables 3&4).

Potential Number of "Takes by Harassment"

Estimated Area Exposed to Sounds ≥160 dB (rms)

The area of water potentially exposed to received levels of airgun sounds ≥160 dB (rms) was calculated by using a GIS to buffer the planned survey tracklines within each water depth category by the associated modeled ≥160 dB (rms) distances. The expected sound propagation from the airgun array was modeled by JASCO Applied Research (Zykov et al. 2010) and is expected to vary with water depth. Survey tracklines falling within the <100 m, 100–1000 m, and >1000 m water depth categories were buffered by distances of 27.8 km, 42.2 km, and 31.6 km, respectively. The total area of water that would be exposed to sound ≥160 dB (rms) on one or more occasions is estimated to be 209,752 km^2. A breakdown by water depth classes used in association with density estimates is presented in Table 5 and Fig. 2.

TABLE 5. Estimated area (km^2) exposed on one or more occasions to airgun sounds with received level ≥160 dB re 1 μPa ((rms), averaged over 90% energy duration) by survey area and water depth.

	Area ensonified (km^2)	
Water Depth (m)	**East survey area**	**West survey area**
<35	-	8758
35–100	-	56813
<100	19045	65571
100–200	2314	5756
200–1000	9585	6701
>1000	61918	38862
Total	**92862**	**116890**

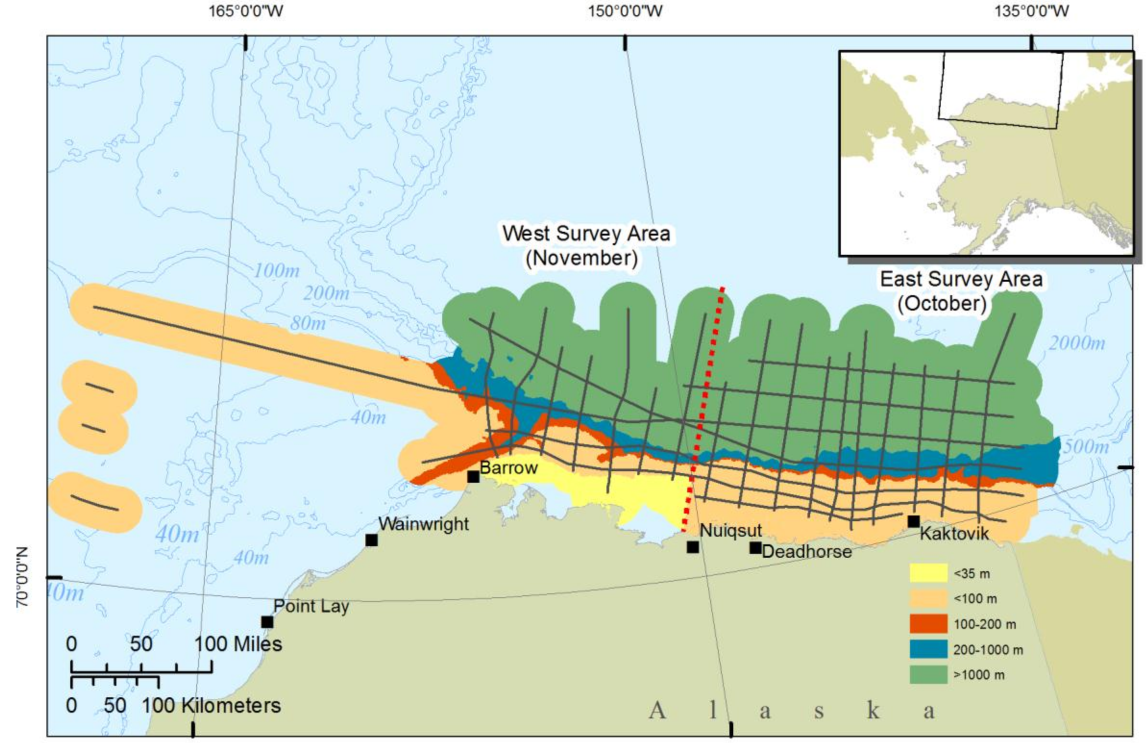

FIGURE 2. Areas estimated to be exposed to airgun sound at received levels ≥160 dB re 1 µPa (rms) by water depth category.

<u>*Best and Maximum Estimates of the Number of Individuals that may be Exposed to ≥160 dB from Seismic Sounds*</u>

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

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

Some of the animals estimated to be exposed, particularly migrating bowhead whales, might show avoidance reactions before being exposed to ≥160 dB re 1 µPa (rms). Thus, these calculations actually estimate the number of individuals potentially exposed to ≥160 dB (rms) if there were no avoidance of the area ensonified to that level. These estimates can also be viewed as representing the number of individuals that would <u>either</u> be potentially exposed to ≥160 dB (rms) <u>or</u> that would show avoidance reactions so as to avoid exposure to ≥160 dB (rms).

Based on the operational plans and marine mammal densities described above, the estimates of marine mammals potentially exposed to sounds ≥160 dB (rms) are presented in Tables 6,7, and 8. For species likely to be present, the requested numbers are calculated as described above. For less common species, estimates were set to minimal numbers to allow for chance encounters. Discussion of the number of potential exposures is summarized by species in the following subsections.

It is likely that some members of one endangered cetacean species (bowhead whale) will be exposed to received sound levels ≥160 dB (rms) unless bowheads avoid the survey vessel before the received levels reach 160 dB (rms). However, the late autumn timing and the design of the proposed survey will minimize the number of bowheads and other cetaceans that may be exposed to seismic sounds generated by this survey. The best estimates of the number of whales potentially exposed to ≥160 dB (rms) are 282 and 4315 for bowheads and belugas, respectively (Table 6).

The ringed seal is the most widespread and abundant pinniped species in ice-covered arctic waters, and there is a great deal of variation in estimates of population size and distribution of these marine mammals. Ringed seals account for the vast majority of marine mammals expected to be encountered, and hence exposed to airgun sounds with received levels ≥160 dB (rms) during the proposed marine survey. It was estimated that ~60,293 ringed seals may be exposed to marine survey sounds with received levels ≥160 dB (rms) if they do not avoid the sound source. Other pinniped species are not expected to be present in the proposed survey area in more than minimal numbers in October–December; however, ION is requesting authorization for a small number of harassment 'takes" of species that occur in the area during the summer months in case a few individuals are encountered (Table 7 & 8).

It should be noted that there is no evidence that most seals exposed to airgun pulses with received levels 160–170 dB re 1 μPa (rms) are disturbed appreciably, and even at a received level of 180 dB (rms) disturbance is not conspicuous (Harris et al. 2001; Moulton and Lawson 2002; see also Appendix C). Therefore, for seals, the estimates of numbers exposed to ≥160 dB re 1 μPa (rms) greatly exceed the numbers of seals that will actually be disturbed in any major or (presumably) biologically significant manner.

TABLE 6. Estimates of the possible numbers of cetaceans that could be exposed to airgun sounds with received levels >160 dB re 1 µPa (rms) during ION's proposed seismic program in the Arctic Ocean, October–December 2011.

	Water Depth							
	<200 m		**200–1000 m**		**>1000 m**		**Total**	
Species	**Avg.**	**Max.**	**Avg.**	**Max.**	**Avg.**	**Max.**	**Avg.**	**Max.**
Beaufort East survey area								
Odontocetes								
Beluga	32	128	1120	4482	2895	11581	4048	16191
Harbor porpoise	2	9	1	4	6	25	9	37
Mysticetes								
Bowhead whale	201	805	3	11	6	25	210	840
Gray whale	2	9	1	4	6	25	9	37
Minke whale	2	9	1	4	6	25	9	37
Humpback whale	2	9	1	4	6	25	9	37
Beaufort West survey area								
Odontocetes								
Beluga	4	17	75	298	182	727	260	1042
Harbor porpoise	3	11	1	3	4	16	7	29
Mysticetes								
Bowhead whale	27	106	0	1	4	16	31	122
Gray whale	3	11	1	3	4	16	7	29
Minke whale	3	11	1	3	4	16	7	29
Humpback whale	3	11	1	3	4	16	7	29
Chukchi survey area								
Odontocetes								
Beluga	7	28	-	-	-	-	7	28
Harbor porpoise	4	17	-	-	-	-	4	17
Mysticetes								
Bowhead whale	41	162	-	-	-	-	41	162
Gray whale	4	17	-	-	-	-	4	17
Minke whale	4	17	-	-	-	-	4	17
Humpback whale	4	17	-	-	-	-	4	17

TABLE 7. Estimates of the possible numbers of pinnipeds that could be exposed to airgun sounds with received levels ≥160 dB re 1 µPa (rms) during the Beaufort East survey area of ION's proposed seismic program in the Arctic Ocean, October–December 2012.[1]

Area	**Beaufort East Survey Area**						**Total**	
Water Depth (m)	**<200**		**200–1000**		**>1000**			
	Avg.	**Max.**	**Avg.**	**Max.**	**Avg.**	**Max.**	**Avg.**	**Max.**
Species								
Ringed seal	1794	7177	805	3221	25	99	2624	10,496
Bearded seal	9	34	4	15	25	99	37	148
Spotted seal	2	9	1	4	6	25	9	37
Ribbon seal	2	9	1	4	6	25	9	37

[1] Most seals exposed to airgun sounds with received levels 160–170 dB re 1 µPa (rms) show no or little overt behavioral response (see text and Appendix C). Therefore, these "exposure" estimates greatly overestimate numbers of seals likely to be disturbed appreciably.

TABLE 8. Estimates of the possible numbers of pinnipeds that could be exposed to airgun sounds with received levels ≥160 dB re 1 µPa (rms) during the Beaufort West and Chukchi survey areas of ION's proposed seismic program in the Arctic Ocean, November–December 2012.[1]

Area Water Depth (m)	**Beaufort West and Chukchi Survey Areas**						**Total**	
	<35 m		**35–200 m**		**>200 m**			
Species	**Avg.**	**Max.**	**Avg.**	**Max.**	**Avg.**	**Max.**	**Avg.**	**Max.**
Beaufort West								
Ringed seal	16,969	19,414	19,393	24,888	18	72	36,380	44,374
Bearded seal	4	14	8	31	18	72	29	117
Spotted seal	1	4	2	8	5	18	7	29
Ribbon seal	1	4	2	8	5	18	7	29
Chukchi								
Ringed seal	-	-	21,289	35,249	-	-	21,289	35,249
Bearded seal	-	-	17	70	-	-	17	70
Spotted seal	-	-	4	17	-	-	4	17
Ribbon seal	-	-	4	17	-	-	4	17

[1] Most seals exposed to airgun sounds with received levels 160–170 dB re 1 µPa (rms) show no or little overt behavioral response (see text and Appendix C). Therefore, these "exposure" estimates greatly overestimate numbers of seals likely to be disturbed appreciably.

Best and Maximum Estimates of the Number of Individuals that may be Exposed to ≥120 dB from Icebreaking Sounds

Most of the sound generated by icebreaking is caused by cavitation of the propellers. Vibrations measured near the bow of the icebreaker *John A. MacDonald* during icebreaking were not correlated with received underwater sounds while vibrations measured at the stern, caused by propeller cavitation, clearly were (Thiele 1984, 1988). Propeller cavitation and resulting sounds tend to be greatest when a vessel is moving astern or when its forward progress has been stopped by heavy ice during ramming. Continuous forward progress through ice requires more power than when a vessel is traveling through open water. The greater the resistance, the greater the propeller cavitation and the greater the resulting sounds, although sound levels during forward progress are typically less strong than during backing and ramming in heavy ice.

Measurements of the icebreaking supply ship *Robert Lemeur* pushing and breaking ice in the Beaufort Sea in 1986 resulted in an estimated broadband source level of 193 dB re 1 µPa · m (Richardson et al. 1995a). These measurements were made on 2 Sep (Greene 1987). Ice conditions were not described in detail, but involved a band of drifting ice pans, presumably composed of second year ice or multi-year ice.

The broadband source levels of three different vessels pushing on or breaking ice during drilling activities in the U.S. Beaufort Sea in 1993 were estimated as 181–183, 184, and 174 dB re 1 µPa · m (Hall et al. 1994). Similar to the above, ice conditions in mid-August when these recordings were made were likely to have been thick first year (sea ice doesn't reach "second year" status until 1 Sep), second year, or multi-year ice.

The strongest sounds produced by an icebreaker backing and ramming an ice ridge were estimated at 203 dB re 1 µPa · m at the point when the propellers were still turning at full ahead but the vessel had come to a stop when it failed to break the ice ridge (Erbe and Farmer 1998). A similar maximum source level (200 dB re 1 µPa · m) was reported during backing and ramming activities by the USCGC *Healy* as measured by a sonobuoy deployed from that vessel in 2009 (Roth and Schmidt 2010).

Roth and Schmidt (2010) includes three very recent "case studies" of *Healy* breaking ice in the high Arctic. Ice type is not described, but given the date, location, and pictures provided, the ice is clearly not juvenile ice and instead likely second year or multi-year ice. The first case study provides an example of *Healy* traveling through 7–9/10ths ice and then entering open-water. Average source levels in ice were estimated to be ~185 dB re 1 µPa · m while average source levels in open-water were estimated between 180 and 175 dB re 1 µPa · m. The second case study is an example of backing and ramming in 8/10ths ice. Maximum source level reached 191–195 dB re 1 µPa · m. The third case study is another example of backing and ramming, this time in 9/10ths ice where maximum source levels reached 200 dB re 1 µPa · m.

None of these examples apply very well to the ice conditions likely to be encountered during the proposed October–December survey. The ice regimes expected to be encountered along the Alaskan Coast in the survey area during the survey period will vary considerably from predominantly or entirely open water in early October to predominantly new young and first year ice in November. The survey will take advantage of such variations to complete the more difficult survey lines when the ice conditions are favorable for that work.

This project will involve two ships working together when in or near sea ice. In this mode the icebreaker (*Polar Prince*) escorts the geophysical ship (*Geo Arctic*). As both ships must move continuously at near survey speed, *it is essential that this work is carried out in ice conditions that do not require the icebreaker to undertake backing and ramming operations*.

ION used the Arctic Ice Regime Shipping System (AIRSS) to aid their determination concerning suitable conditions for the survey. This system allows the Arctic Mariner/Ice Master to calculate the "toughness" of a particular ice regime. As a "rule of thumb" ice-seismic is normally considered achievable in ice where the calculation indicates navigation can safely be undertaken by the ice strengthened (Ice Class A1A, type A) geophysical ship, operating independently. We then greatly augment this safety factor with an escort icebreaker. This means the icebreaker is normally working very lightly but does have a large propulsive power capacity held in reserve in case small ridges or other such ice features are encountered. Thus, the icebreaker is breaking ice at a fraction of its maximum or rated capacity.

Compared to the aggressive icebreaking involved in the examples above, the icebreaking for ice-seismic is of a much different and considerably lower order. In most ice regimes expected to be encountered during the survey the *Polar Prince* will have about 5,123 HP available for propulsion, which is far less than the power of the heavy icebreaker *Healy* reported in Roth and Schmidt (2010). There would still be a direct correlation between icebreaking effort and icebreaking noise, although we should expect there are also many other variables such as thermal gradient, stage of ice development, speed of impact, propulsion system characteristics, hull and bow form, etc., that may differentiate the sounds produced during the proposed survey. In the examples provided in Roth and Schmidt (2010), the *Healy* appears to be backing and ramming in heavy multiyear ice (based on our interpretation of the pictures). Such conditions are beyond the allowable operational conditions of this project and if such conditions were encountered, the Type A geophysical ship could not follow such an ice-encumbered track of multiyear ice.

It should also be noted that the *Healy* was operating at maximum capacity during the measurements reported in Roth and Schmidt (2010), while during ice-seismic the escorting icebreaker rarely operates in excess of 50% capacity. Thus, accounting for the disparity in the horsepower ratings of the *Polar Prince* vs. the *Healy*, the *Polar Prince* is rendering an output, in terms of horsepower expended, of <25% each of that of the *Healy* during the reported measurements.

Based on available information regarding sounds produced by icebreaking in various ice regimes and the expected ice conditions during the proposed survey, we believe that vessel sounds generated during ice breaking are likely to have source levels between 175 and 185 dB re 1 µPa · m. As described above, we have assumed that seismic survey activity will occur along all of the planned tracklines shown in Figure 1. Therefore, we have applied the seismic ≥160 dB radius of 26.7–42.2 km (depending on water depth) to each side of all of the survey lines as shown in Figure 2. Assuming a source level of 185 dB re 1 µPa · m and 15logR spreading, icebreaking sounds may be ≥120 dB out to a maximum distance of ~21.6 km. Thus, all sounds produced by icebreaking are expected to diminish below 120 dB re 1 µPa within the zone where we assume mammals will be exposed to ≥160 dB (rms) from seismic sounds. Exposures of marine mammals to icebreaking sounds with received levels ≥120 dB would effectively duplicate or "double-count" animals already included in the estimates of exposure to strong (≥160 dB) airgun sounds. The planned survey lines cover a large extent of the U.S. Beaufort Sea, and seismic survey activity along all those lines has been assumed in the estimation of takes. Any non-seismic periods, when only icebreaking might occur, would therefore result in fewer exposures than estimated from seismic activities.

If refueling of the *Geo Arctic* is required during the survey and then the *Polar Prince* transits to and from Canadian waters to acquire additional fuel for itself, an additional ~200 km of transit may occur.

Most of this transit would likely occur through ice in offshore waters >200 m in depth. For estimation purposes we have assumed 25% of the transit will occur in 200–1000 m of water and the remaining 75% will occur in >1000 m of water. This results in an estimated ~2160 km^2 of water in areas 200–1000 m deep and 6487 km^2 in waters >1000 m deep being ensonified to ≥120 dB by icebreaking sounds. Using the density estimates for the east survey area shown in Tables 2 and 3, the estimated exposures of cetaceans and pinnipeds are shown in Tables 9 and 10.

If the *Polar Prince* cannot return to port via Canadian waters, then a transit of ~600 km from east to west across the U.S. Beaufort would be necessary. Again, we expect that most of this transit would likely occur in offshore waters >200 m in depth. For estimation purposes we have assumed 25% of the transit will occur in 200–1000 m of water and the remaining 75% will occur in >1000 m of water. This results in an estimated ~3240 km^2 of water in areas 200–1000 m deep and 9720 km^2 in waters >1000 m deep being ensonified to ≥120 dB by icebreaking sounds within each half of the U.S. Beaufort Sea, for a total of 25,920 km^2 ensonified across the entire U.S. Beaufort Sea. Using the density estimates in Tables 2–4, estimated exposures of cetaceans and pinnipeds are shown in Tables 11 and 12.

TABLE 9. Estimates of the potential numbers of cetaceans exposed to ≥120 dB re 1 µPa (rms) during icebreaking activities associated with the preferred alternative for refueling during ION's proposed seismic program in the Beaufort Sea, October–December 2010.

	Water Depth (m)				**Total**	
	200–1000		**>1000**			
Species	**Avg.**	**Max.**	**Avg.**	**Max.**	**Avg.**	**Max.**
Odontocetes						
Beluga	253	1010	320	1281	573	2291
Harbor porpoise	0	1	1	3	1	4
Mysticetes						
Bowhead whale	1	2	1	3	1	5
Gray whale	0	1	1	3	1	4
Minke whale	0	1	1	3	1	4
Humpback whale	0	1	1	3	1	4

TABLE 10. Estimates of the potential numbers of pinnipeds exposed to ≥120 dB re 1 µPa (rms) during icebreaking activities associated with the preferred alternative for refueling during ION's proposed seismic program in the Beaufort Sea, October–December 2010.

	Water Depth				**Total**	
	200–1000		**>1000**			
Species	**Avg.**	**Max.**	**Avg.**	**Max.**	**Avg.**	**Max.**
Ringed seal	181	726	3	11	184	737
Bearded seal	1	3	3	11	4	14
Spotted seal	0	1	1	3	1	4
Ribbon seal	0	1	1	3	1	4

TABLE 11. Estimates of the potential numbers of cetaceans exposed to ≥120 dB re 1 µPa (rms) during icebreaking activities associated with the secondary alternative for refueling during ION's proposed seismic program in the Beaufort Sea, October–December 2010.

	Water Depth (m)				**Total**	
	200–1000		**>1000**			
Species	**Avg.**	**Max.**	**Avg.**	**Max.**	**Avg.**	**Max.**
Beaufort East survey area						
Odontocetes						
Beluga	379	1515	455	1818	833	3333
Harbor porpoise	0	1	1	4	1	5
Mysticetes						
Bowhead whale	1	4	1	4	2	8
Gray whale	0	1	1	4	1	5
Minke whale	0	1	1	4	1	5
Humpback whale	0	1	1	4	1	5
Beaufort West survey area						
Odontocetes						
Beluga	38	152	45	182	83	333
Harbor porpoise	0	1	1	4	1	5
Mysticetes						
Bowhead whale	0	0	1	4	1	4
Gray whale	0	1	1	4	1	5
Minke whale	0	1	1	4	1	5
Humpback whale	0	1	1	4	1	5

TABLE 12. Estimates of the potential numbers of pinnipeds exposed to ≥120 dB re 1 µPa (rms) during icebreaking activities associated with the secondary alternative for refueling during ION's proposed seismic program in the Beaufort Sea, October–December 2010.

	Water Depth				**Total**	
	200–1000		**>1000**			
Species	**Avg.**	**Max.**	**Avg.**	**Max.**	**Avg.**	**Max.**
Beaufort East survey area						
Ringed seal	272	1089	4	16	276	1104
Bearded seal	1	5	4	16	5	21
Spotted seal	0	1	1	4	1	5
Ribbon seal	0	1	1	4	1	5
Beaufort West survey area						
Ringed seal	1	5	4	16	5	21
Bearded seal	1	5	4	16	5	21
Spotted seal	0	1	1	4	1	5
Ribbon seal	0	1	1	4	1	5

Estimates of the Number of Individuals that may be Exposed to ≥180 dB (Cetaceans) and ≥190 dB (Pinnipeds) from Seismic Sounds

As noted previously in this application, the inclusion of estimates of potential exposures of marine mammals to seismic sounds with received levels ≥180 dB or ≥190 dB for purposes of estimating "level A" takes has been included at the specific request of NMFS. Communications received from NMFS have noted that poor visibility of the 180 and 190 dB re 1 µPa (rms) zones caused by ice cover and long periods of darkness increase the potential for multiple exposures to sounds ≥180 or ≥190 dB which may induce TTS. This increased potential for inducing TTS is the reason that estimation of "level A" takes has been requested. However, scientific consensus is that mild TTS is not injury (Southall et al. 2007), and therefore should not be considered a Level A or "injurious" take. The methods used below for estimating the number of individuals potentially exposed to sounds >180 or >190 dB should therefore include an additional reduction to estimate the number that may incur PTS, which is presumably a Level A take. For reasons described here, in § IV, and further below, ION does not believe that marine mammals will be injured or harmed by the proposed project.

Most cetaceans (and particularly Arctic cetaceans) show relatively high levels of avoidance when received sound pulse levels exceed 160 dB re 1 µPa (rms), and it is very uncommon to sight any Arctic cetacean within the 180 dB distance. Results from monitoring programs associated with seismic activities in the Arctic have shown significant responses by cetaceans at levels lower than 180 dB. These results have been used by agencies to support monitoring requirements within distances where received levels reach 160 dB (rms) and as low as 120 dB (rms). Thus, very few (if any) cetaceans would be exposed to sound levels of 180 dB re 1 µPa (rms) regardless of detectability by MMOs. Avoidance varies among individuals and depends on their activities or reasons for being in the area, and occasionally a few individual Arctic cetaceans will tolerate sound levels above 160 dB. Even so, tolerance of levels above 180 dB by Arctic cetaceans is very infrequent regardless of the circumstances. Therefore, a theoretical calculation of the number of cetaceans potentially exposed to ≥180 dB that is based simply on density in the absence of nearby seismic operations would be a gross overestimate of the actual numbers that might be exposed to 180 dB. Such calculations would be misleading unless avoidance response behaviors were taken into account to estimate what fraction of those originally present within the soon-to-be ensonified-to-≥180 dB zone (as estimated from density) would still be there by the time levels reach 180 dB.

Only two cetacean species, beluga and bowhead, are likely to be present in the Alaskan Beaufort Sea late in the survey period or where extensive ice cover is present. Gray whale vocalizations have been recorded throughout one winter (2003–2004) in the western Alaskan Beaufort Sea near Pt. Barrow (Moore et al. 2006). In the fall, gray whales may be dispersed more widely through the north-eastern Chukchi Sea (Moore et al. 2000), but overall densities are likely to be decreasing as the whales begin migrating south. The presence of gray whales in November in the proposed survey area does not appear to be a regular occurrence or involve a significant number of animals when it does occur. We therefore believe that exposures of cetacean species other than beluga or bowhead to received sound levels ≥180 dB during periods of darkness or in areas with extensive ice cover will not occur.

Beluga whales have shown avoidance of icebreaking sounds at relatively low received levels. In the Canadian Arctic belugas showed initial avoidance of ship and icebreaking sounds at received levels from 94–105 dB in the 20–1000 Hz band, although some animals returned to the same location within 1–2 days and tolerated noise levels as high as 120 dB in that band (Finley et al. 1990). Playback experiments with icebreaker sounds resulted in 35% of beluga groups showing avoidance at received levels between 78 and 84 dB in the 1/3-octave band centered at 5000 Hz, or 8–14 dB above ambient levels (Richardson et al. 1995b). Based on these results it was estimated that reactions by belugas to an actual icebreaker would likely occur at ~10 km under similar conditions. Erbe and Farmer (2000) estimated that zones of disturbance from icebreaking sounds could extend 19–46 km depending on various factors. Erbe and Farmer (2000) also estimated that a beluga whale would have to remain within 2 km of an icebreaker backing and ramming for over 20 min to incur mild TTS (4.8 dB), and within 120 m for over 30 min to incur more significant TTS (12–18 dB).

Aerial and vessel based monitoring of seismic surveys in the central Beaufort Sea showed significant avoidance of active airguns by belugas. Results of the aerial monitoring suggested an area of avoidance out to 10–20 km around an active seismic source with higher than expected sighting rates observed at distances 20–30 km from the source (Miller and Davis 2002). The nearest aerial "transect" beluga sighting during seismic activity was at a distance of 7.8 km. Only seven beluga sightings were recorded from the survey vessel during the entire study, three of which occurred during airgun activity. Two of the seismic period sightings were made at the beginning of active airgun periods and the other was during seismic testing of a limited number of guns. These sightings occurred at distances between 1.54 km and 2.51 km from the vessel. Similarly, few beluga whales were observed near seismic surveys in the Alaskan Beaufort Sea in 1996–1998 (Richardson 1999). However, the beluga migration corridor is typically well offshore of where most of the 1996–1998 seismic surveying occurred. During 2006–2008, observers on seismic and associated support vessels operating in the Alaskan Beaufort Sea reported no beluga sightings during seismic or non-seismic periods, suggesting avoidance of both seismic and vessel sounds (Savarese et al. 2010). Again, the main migration corridor for belugas was farther offshore than the seismic operations. No mitigation of seismic operations (power down or shut down of airgun arrays) has been necessary as a result of beluga sightings during seismic surveys in the Chukchi or Alaskan Beaufort seas in 2006–2009 (Ireland et al. 2007a,b; Patterson et al. 2007; Funk et al. 2008; Ireland et al. 2009; Reiser et al. 2010).

Based on the reported avoidance of vessel, icebreaking, and seismic sounds by beluga whales, and the low and seasonally decreasing density during the time of the proposed survey, the likelihood of beluga whales occurring within the ≥180 dB zone during the proposed project is extremely low. A cautionary estimate that assumes 10% of belugas will show no avoidance of the 180 dB zone results in an estimate of 23 beluga whales exposed to sounds ≥180 dB (based on the densities described above and the area of water that may be ensonified to ≥180 dB) during the proposed project.

Bowhead whales have shown similar avoidance of vessel and seismic sounds. Less information is available regarding avoidance of icebreaking sounds; however, avoidance of the overall activity was noted during intensive icebreaking around drillsites in the Alaskan Beaufort Sea in 1992. Migrating bowhead whales appeared to avoid the area of drilling and icebreaking by ~25 km (Brewer et al. 1993). Also, monitoring of drilling activities in a previous year, during which much less icebreaking occurred, showed avoidance by migrating bowheads out to ~20 km. Therefore the relative influence of icebreaking versus drilling sounds is difficult to determine.

Similarly, migrating bowheads strongly avoided the area within ~20 km of nearshore seismic surveys, and less complete avoidance extended to ~30 km (Miller et al. 1999). Only 1 bowhead was observed from the survey vessel during the three seasons (1996–1998) when seismic surveys continued into September. Bowheads not actively engaged in migration have shown less avoidance of seismic operations. During seismic surveys in the Canadian Beaufort Sea in late August and early September bowhead whales appeared to avoid an area within ~2 km of airgun activity (Miller and Davis 2002) and sightings from the survey vessel itself were common (Miller et al. 2005). Vessel based sightings showed a statistically significant difference of ~600 m in the mean sighting distances of bowheads (relative to the survey vessel) between periods with and without airgun activity. This, along with significantly lower sighting rates of bowhead whales during periods of airgun activity, suggests that bowheads still avoided close approach to the area of seismic operation (Miller and Davis 2002). Results from vessel-based and aerial monitoring in the Alaskan Beaufort Sea during 2006–2008 were similar to those described above (Funk et al. 2010). Sighting rates from seismic vessels were significantly lower during airgun activity than during non-seismic periods. Support vessels reported 12 sightings of bowhead whales in areas where received levels from seismic were ≥160 dB (Savarese et al. 2010). Aerial surveys reported bowhead whales feeding in areas where received levels of seismic sounds were up to 160 dB. Bowheads were not observed in locations with higher received levels (Christie et al. 2010). Based on four direct approach experiments in northern Alaskan waters, Ljungblad et al. (1988) reported total avoidance of seismic sounds at received sound levels of 152, 165, 178, and 165 dB.

The available information summarized above suggests that bowhead whales are very likely to avoid areas where received levels are ≥180 dB re 1 μPa (rms). Again, making a cautionary assumption that as many as 10% of bowheads may not avoid the 180 dB zone around the airguns, we calculate that 6 individuals could be exposed to ≥180 dB (based on the densities described above and the area of water that may be ensonified to ≥180 dB). During seismic surveys in the Alaskan Beaufort Sea in 2007 and 2008, 5 power downs of the full airgun array were made due to sightings of bowhead or unidentified mysticete whales (8 total individuals) within the ≥180 dB safety zone. These sightings occurred during >8000 km of survey effort in good conditions plus additional effort in poor conditions (Savarese et al. 2010), resulting in an estimated 0.625 sightings within the 180 dB distance per 1000 km of seismic activity. Even without allowance for the reduced densities likely to be encountered in October and especially November, or for the fact that observers will be on duty during all daylight hours and will call for mitigation actions if whales are sighted within or near the 180 dB distance, this rate would suggest that fewer than 8 bowheads may occur within the ≥180 dB zone during the proposed survey.

For ***seals*** (principally ringed seals), the proportion exhibiting avoidance is lower than for cetaceans, and thus the received level at which avoidance becomes evident is higher. However, some survey results have shown a statistically significant avoidance of the 190 dB re 1 μPa (rms) zone, and an assumption that numbers exposed to ≥190 dB could be calculated from “non-seismic” density data is not inappropriate. Using similar reasoning as described above for cetaceans, we have limited these estimates to ringed seals as the presence of other pinniped species is very unlikely during the times and locations when exposures to ≥190 dB may have an increased likelihood of occurrence.

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

During more recent seismic surveys in the Arctic (2006–2009), Reiser et al. (2009) also reported a tendency for localized avoidance of areas immediately around the seismic source vessel along with coincident increased sighting rates at support vessels operating 1–2 km away. However, pinnipeds were sighted within the 190 dB zone around the operating airguns more frequently than were cetaceans within the 180 dB zone. Assuming that 25% of the ringed seals encountered may not avoid the 190 dB zone as the airguns approach, we calculate that ~277 individuals could be exposed to ≥190 dB (based on the densities described above and the area of water that may be ensonified to ≥190 dB). As an alternative estimate, during the same >8000 km of monitoring effort in the Alaskan Beaufort Sea reported above regarding bowhead whales, 42 observations of seals within the 190 dB zone caused power downs of the airguns. This was ~5.25 power downs per 1000 km of seismic survey effort. Even without allowance for the reduced densities of seals likely to be encountered in October–November or for the fact that observers will be on duty during all daylight hours and will call for mitigation actions if necessary, this rate would suggest that as many as 38 seals may occur within the ≥190 dB zone during the proposed survey.

Conclusions

Cetaceans

It is likely that some bowhead and beluga whales will remain in the Alaskan Beaufort and Chukchi seas during the seismic survey and some of those could be exposed to seismic sounds with received levels ≥160 dB re 1 µPa (rms) or icebreaking sounds ≥120 dB. However, most whales will have migrated out of the proposed survey area and will not be present. Furthermore, the spatial and temporal design of the proposed survey will minimize encounters with whales. If belugas or bowheads are approached during the survey, most of them will likely show avoidance of airgun sounds at received levels ≥160 dB re 1 µPa (rms), and few if any are expected to receive ≥180 dB (rms). Other cetacean species, including gray whale, humpback whale, fin whale, minke whale, and harbor porpoise, are not expected to be present during October–December.

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

For species listed as endangered under the ESA, the only species likely to be in the area during operations and exposed to received levels ≥160 dB (rms) is the bowhead whale, and it is estimated that as many as 282 bowheads could be exposed at this level, or would show avoidance before received sound levels reach 160 dB. The total represents ~2 % of the Bering–Chukchi–Beaufort population of bowhead whales, which is estimated to be >15,233 in 2012 assuming 3.4% annual population growth from the 2001 estimate of >10,545 animals (Zeh and Punt 2005).

The only other cetacean species likely to be present in the study area is the beluga whale, and it is estimated that as many as 4315 belugas may be exposed to sound at received levels ≥160 dB (rms) or would show avoidance before received sound levels reach 160 dB. This represents ~11% of the Beaufort Sea population (Allen and Angliss 2011).

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 the sequence of locations where shooting will occur, controlled vessel speed, dedicated marine mammal observers, non-pursuit, and shut downs or power downs when marine mammals are seen within defined ranges will further reduce short-term reactions and minimize any effects on hearing sensitivity. In all cases, the effects are expected to be short-term, with no lasting biological consequence.

Pinnipeds

Ringed seal is the only pinniped species likely to be present in the survey area in significant numbers. The best estimate of the numbers of individual seals exposed to airgun sounds at received levels ≥160 dB (rms) during the survey is 60,293 ringed seals. However, this estimate does not take into consideration the fact that some proportion of those seals will be hauled out on ice and therefore not exposed to seismic sounds at received levels ≥160 dB (rms). It is also possible that relatively small numbers of bearded, spotted, and ribbon seals may be exposed to those levels of airgun sound during the proposed survey. It is estimated that 91 bearded seals, 22 spotted seals, and 22 ribbon seals may be exposed to seismic sounds at received levels ≥160 dB (rms); however this represents less than 1-2% of those populations (Allen and Angliss 2011). As discussed earlier, most seals exposed to ≥160 dB (rms) are expected to show no overt disturbance response. The short-term exposures of seals to airgun sounds are not expected to result in any long-term negative consequences for the individuals or their populations.

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; Braund and Kruse 2009). 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.

Subsistence Hunting

Marine mammals are legally hunted in Alaskan waters by coastal Alaska Natives; species hunted include bowhead and beluga whales; ringed, spotted, and bearded seals; walruses, and polar bears. The importance of each of the various species varies among the communities based largely on availability. Bowhead whales are the marine mammal species primarily harvested during the time of the proposed seismic survey. Subsistence remains the basis for Alaska Native culture and community, and subsistence activities are often central to many aspects of human existence, including patterns of family life, artistic expression, and community religious and celebratory activities.

Bowhead whale hunting is a key activity in the subsistence economies of Barrow and other Native communities along the Beaufort Sea and Chukchi Sea coast. 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 during five-year periods (USDI/BLM 2005). The NMFS recently proposed continuation of the bowhead hunt for the five-year period 2008–2012 (NMFS 2008b).

The community of Barrow hunts bowhead whales in both the spring and fall during the whales' seasonal migrations along the coast (Fig. 3). 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 13). The communities of Nuiqsut and Kaktovik participate only in the fall bowhead harvest. The fall migration of bowhead whales that summer in the eastern Beaufort Sea typically begins in late August or September. Fall migration into Alaskan waters is primarily during September and October. However, in recent years a small number of bowheads have been seen or heard offshore from the Prudhoe Bay region during the last week of August (Treacy 1993; LGL and Greeneridge 1996; Greene 1997; Greene et al. 1999; Blackwell et al. 2004).

The spring hunts at Wainwright and Barrow occur after leads open due to the deterioration of pack ice; the spring hunt typically occurs from early April until the first week of June. The location of the fall subsistence hunt depends on ice conditions and (in some years) industrial activities that influence the bowheads as they move west (Brower 1996). The fall migration of bowhead whales that summer in the eastern Beaufort Sea typically begins in late August or September. Fall migration through Alaskan waters is primarily during September and October. 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 fall hunts begin in late August or early September in Kaktovik and at Cross Island. At Barrow the fall hunt usually begins in mid-September, and mainly occurs in the waters east and northeast of Point Barrow. In 2007 however, all bowheads taken in fall at Barrow were harvested west of Pt. Barrow in the Chukchi Sea (Suydam et al 2008). The whales have usually left the Beaufort Sea by late October (Treacy 2002a,b).

The scheduling of this seismic survey was introduced to representatives of those concerned with the subsistence bowhead hunt including the AEWC and the North Slope Borough (NSB) Department of Wildlife Management during a meeting in Barrow on 15 Dec. 2009. Additional meetings occurred in 2010, 2011, and 2012 with more planned later in 2012 to share information regarding the survey with other members of the subsistence hunting community. The timing of the proposed geophysical survey in October–December will not affect the spring bowhead hunt. The fall bowhead hunt may be occurring near Barrow during October, and operations will be coordinated with the AEWC. ION will operate at the eastern end of the survey area until fall whaling in the Beaufort Sea near Barrow is finished.

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). The timing of the proposed survey will not overlap with the beluga harvest.

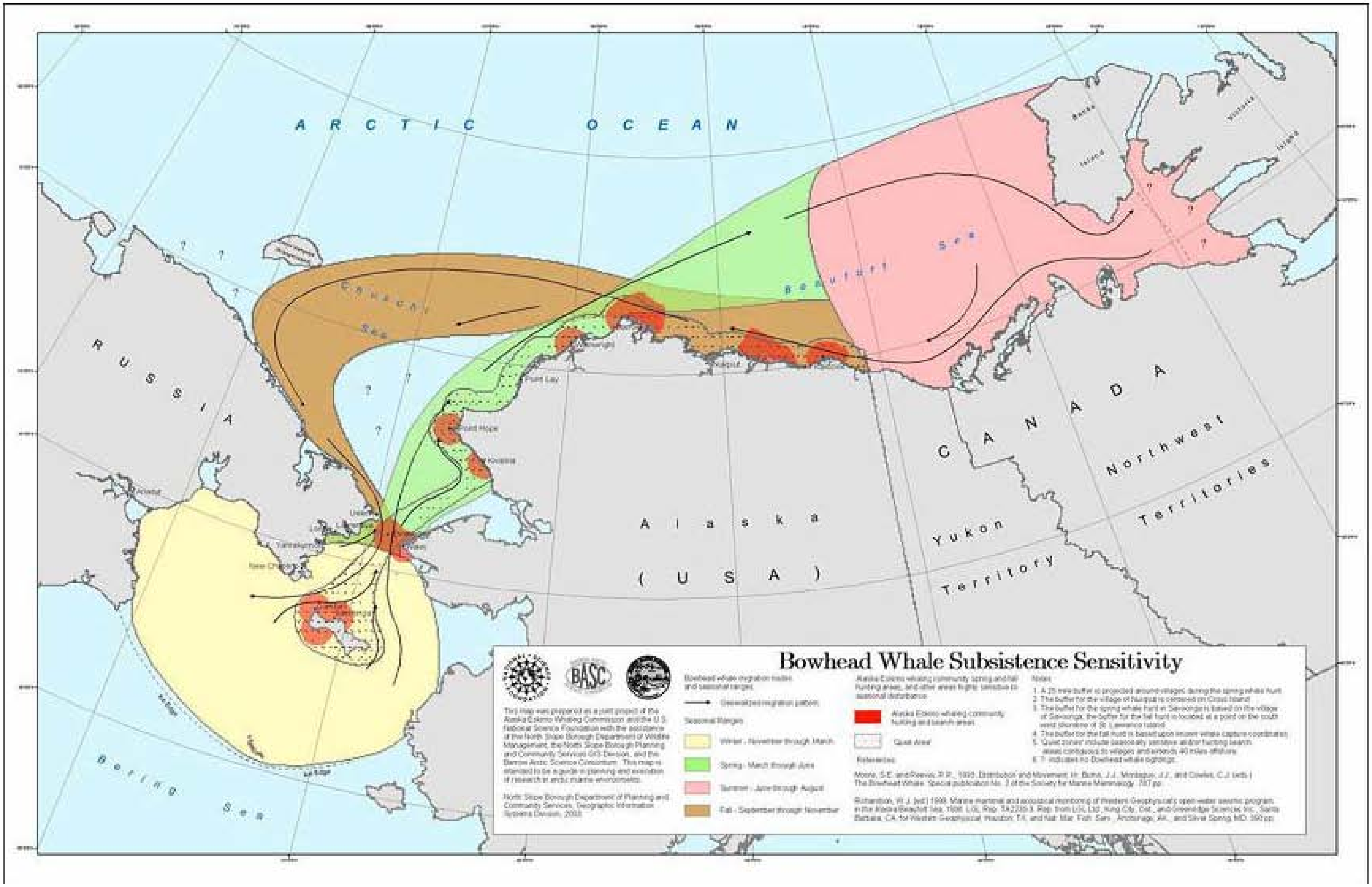

FIGURE 3. Bowhead subsistence harvest areas indicating the extent offshore where subsistence hunting is conducted (NSF 2004).

TABLE 13. Number of bowhead whale landing by year at Barrow, Cross Island (Nuiqsut), and Kaktovik, 1993-2008. Barrow numbers include the total number of whales landed for the year followed by the numbers landed during the fall hunt in parenthesis.

Year	Barrow	Cross Island	Kaktovik	Wainwright
1993	23(7)	3	3	5
1994	16(1)	0	3	4
1995	20(11)	4	4	5
1996	24(19)	2	1	3
1997	31(21)	3	4	3
1998	25(16)	4	3	3
1999	24(6)	3	3	5
2000	18(13)	4	3	5
2001	26(7)	3	4	6
2002	20(17)	4	3	?
2003	16(6)	4	3	?
2004	21(14)	3	3	4
2005	29	1	3	-
2006	22	4	3	-
2007	20	3	3	-
2008	21	4	3	-
2009	19(15)	?	3	1
2010	22(8)	?	3	2

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

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

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

4 2009-2010 numbers from AEWC Final Reports

Ringed seals are hunted 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. In winter, leads and cracks in the ice off points of land and along the barrier islands are used for hunting ringed seals. The average annual ringed seal harvests by the various communities are presented in Table 14. The seismic survey will be largely in offshore waters where the activities will not influence ringed seals in the nearshore areas where they are hunted.

The ***spotted seal*** subsistence hunt peaks in July and August, at least in 1987 to 1990, but involves few animals. Spotted seals typically migrate south by October to overwinter in the Bering Sea, and therefore the proposed October–December survey will not affect hunting of this species. Admiralty Bay, <60 km to the east of Barrow, is a location where spotted seals are harvested. Spotted seals are also occasionally hunted in the area off Point Barrow and along the barrier islands of Elson Lagoon to the east

(USDI/BLM 2005). The average annual spotted seal harvest by the community of Barrow from 1987–1990 was one (Braund et al. 1993; Table 14.

TABLE 14. Average annual take of marine mammals other than bowhead whales harvested by the community of Barrow, Point Lay, and Wainwright.

	Walruses	**Beluga Whales**	**Ringed Seals**	**Bearded Seals**	**Spotted Seals**
Point Lay	3	31	49	13	53
Wainwright	58	8	86	74	12
Barrow	46	2	394	175	4

[a] Includes one or more harvests from 1987-1999 (Braund et al. 1993; USDI/BLM 2003, 2005)

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 (~15 mi) of Point Barrow. The average annual take of bearded seals by the Barrow community from 1987 to 1990 was 174 (Table 14). Because bearded seal hunting typically occurs during the summer months, the proposed October–December survey is not expected to affect bearded seal harvests.

Subsistence Fishing

Subsistence fishing is conducted throughout the year, but most actively occurs during the summer and fall months. Fishing is often a source of food in the hunting camps, so the geographic range of subsistence fishing is widespread. Marine subsistence fishing occurs during the harvest of other subsistence resources in the summer. Most fishing occurs in coastal areas and thus well away from the offshore waters where a majority of the proposed survey will be conducted (MMS 1996).

Seismic surveys can, at times, cause changes in the catchability of fish. In the unlikely event that subsistence fishing (or hunting) is occurring within 5 km of the *Geo Arctic's* trackline, or within other situations inconsistent with the Plan of Cooperation (POC), the airgun operations will be suspended until the vessel is >5 km away and otherwise in compliance with the POC. The location of the proposed geophysical survey however, is well offshore and far from any subsistence fishing activities

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 their food sources. 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. Icebreaking could alter ice conditions in the immediate area around the vessels. However, ice conditions at this time of year are typically highly variable and relatively unstable in most locations the survey will take place. Icebreaking has the potential to destroy ringed seal lairs or polar bear dens, which will be further discussed in §X. However, these animals are not expected to enter subnivean structures until later in the season. Smith and Stirling (1975) reported that ringed seal lairs were found in a minimum snow depth of 20 cm and a maximum of 150 cm. The survey vessels will likely leave the area before the snow is thick enough for seals to form lairs or the ice is stable enough to support permanent polar bear dens.

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, the primary food sources of pinnipeds and belugas, is 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; Wardle et al. 2001). Generally, the higher the received pressure and the less time required 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 from the sound source. The proposed surveys would occur well offshore away from nearshore waters where most subsistence fishing activities occur.

The only designated Essential Fish Habitiat (EFH) species in the area of the proposed project during the seismic survey are salmon (adult), and their occurrence in waters north of the Alaska coast is limited. Adult fish near seismic operations are likely to avoid the immediate vicinity of 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 seismic program in the Beaufort and Chukchi seas for 2012 is predicted to have negligible effects on the various life stages of fish and invertebrates.

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 their food sources. The main impact issue associated with the proposed activities will be temporarily elevated noise levels and their associated direct effects on marine mammals, as discussed above, as well as the potential effects of icebreaking. The potential effects of icebreaking include locally altered ice conditions and the potential for the destruction of ringed seal lairs or polar bear dens. However, these animals are not expected to enter these structures until later in the season. Ice conditions at this time of year are typically quite variable with new leads opening and pressure ridges forming as wind and waves move the newly forming ice. This dynamic environment may be responsible for the mean date of permanent den entry on sea ice in the Beaufort Sea being later than on land (Amstrup and

Gardner 1994). The icebreaker and seismic vessel transit is not expected to significantly alter the formation of sea ice during this period.

Icebreaking will open leads in the sea ice along the vessel tracklines and could potentially destroy ringed seal lairs or polar bear dens. However, ringed seals will not need lairs for pupping until the late winter or spring, so the impacts are not expected to impact pup survival. Ringed seals excavate lairs in snow that accumulates on sea ice near their breathing holes, and an individual seal maintains several breathing holes (Smith and Stirling 1975). Ringed seal lairs are found in snow depths of 20–150 cm (Smith and Stirling 1975), and seals are not expected to enter lairs before the survey takes place. Damage to lairs caused by survey activities is not expected to exceed that which occurs naturally, and lair destruction in the early winter would likely not impact ringed seal survival. Lanugal pups born in the spring can become hypothermic if wetted, but by early winter they are robust to submersion having spent the entire summer at sea (Smith et al. 1991). The highest density of ringed seals reported from aerial surveys conducted during spring when seals were emerging from lairs was in areas with water depth ranging from 5–35 m (Frost et al. 2004). A relatively small proportion (5%; 364 km) of the proposed survey trackline is planned in that area.

During the seismic survey only a small fraction of the available habitat would be ensonified at any given time. Disturbance to fish species would be short-term and fish would return to their pre-disturbance behavior once the seismic activity ceases (McCauley et al. 2000a,b; Santulli et al. 1999; Pearson et al. 1992). Thus, the proposed survey would have little, if any, impact on the abilities of marine mammals to feed in the area where seismic work is planned.

Some mysticetes, including bowhead whales, feed on concentrations of zooplankton. Some feeding bowhead whales may occur in the Alaskan Beaufort Sea in July and August, and others feed intermittently during their westward migration in September and October (Richardson and Thomson [eds.] 2002; Lowry et al. 2004; Lyons et al. 2009; Christi et al. 2010). A reaction by zooplankton to a seismic impulse would only be relevant to whales if it caused concentrations 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. Bowhead whales are expected to be migrating during the period of the proposed survey and will not likely be feeding in the area.

Refueling at sea has the potential to impact the marine environment if a spill were to occur. However, there are multiple procedures and safeguards in place to avoid such an accident. Prior to conducting a fuel transfer the area around the vessels would be checked for the presence of marine mammals and operations delayed until the area was clear. A leak during refuleing would be detected and the system shut down within a maximum of 30 seconds. The diesel oil transfer pump is rated at 50 IGPM @ 60 ft pressure head (From ships drawing 3095-18). Therefore, the maximum amount of oil that could be spilled during a transfer is 25 imperial gallons. This risk is reduced further with the standard use of 'dry-break' fittings (new or not prior to 2010) for fuel transfers.

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.

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

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

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

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

Survey Timing

The early winter timing of the proposed survey will minimize encounters with marine mammals because most species will have migrated south for the winter. The survey will begin in offshore waters of the eastern U.S. Beaufort Sea deeper than 1000 m, where bowhead whale density is expected to be the lowest in the survey area. The survey will then progress from east to west across the U.S. Beaufort Sea, including nearshore waters, beginning in mid-October. Operations will be restricted to the east survey area until late October or early November in order to minimize interactions with westward-migrating bowhead whales and avoid disturbing the bowhead subsistence hunt near Barrow that typically concludes by mid-October.

Marine Mammal Monitoring

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

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

Further details on marine mammal monitoring methodology and data collection are provided in § XIII.

Proposed Safety Radii

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

Received sound levels were modeled for the full 26 active airgun, 4450 in^3 array in relation to distance and direction from the source (Zykov et al. 2010). Based on the model results, Table 15 shows the distances from the airguns where ION predicts that sound levels of 190, 180, and 160 dB re 1 µPa (rms) will be received. A single 70-in^3 airgun will be used as a mitigation gun during turns or if a power down of the full array is necessary due to the presence of a marine mammal within or about to enter the applicable safety radius of the full airgun array. Underwater sound propagation of a 30 in^3 airgun was measured in <100 m of water near Harrison Bay in 2007 and results were reported in Funk et al. (2010). The constant term of the resulting equation was increased by 2.45 dB based on the difference between the volume of the two airguns [2.45 = 20Log(70/30)^(1/3)]. The 190 dB and 180 dB distances from the adjusted equation, 19 m and 86 m respectively, will be used as the safety zones around the single 70 in^3 airgun in all water depths until results from field measurements are available.

TABLE 15. Distances to which sound is estimated to propagate by water depth and received sound level.

Received Sound Level (dB re 1µPa rms)	**Water Depth (m)**		
	<100	**100-1000**	**>1000**
190	600	180	180
180	2,850	660	580
160	27,800	42,200	31,600

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

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

Mitigation during Operations

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

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

- During foggy conditions or darkness the full 180 dB (rms) safety radius may not be visible. In that case, the airguns could not start up after a full shut down until the entire 180 dB radius was visible.
- During any nighttime operations, if the 180 dB safety radius is visible using vessel lights, NVDs[2] and/or FLIR, then start up of the airgun array may occur following a 30 min period of observation without sighting marine mammals in the safety radius.
- If one or more airguns have been operational before nightfall, they can remain operational throughout the night, even though the entire safety radius may not be visible.

Speed or Course Alteration

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

Power Down Procedures

A power down involves decreasing the number of airguns in use such that the radii of the 190 dB (rms) and 180 dB (rms) zones are decreased to the extent that observed marine mammals are not in the applicable safety zone. A power down may also occur when the vessel is moving from one seismic line to another. During a power down, one airgun (or some other number of airguns less than the full airgun array) is operated. The continued operation of one airgun is intended to (a) alert marine mammals to the

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[2] See Smultea and Holst (2003), Holst (2004), Smultea et al. (2004), Stoltz and MacLean *in* MacLean and Koski (2005), and Hartin et al (2011) for an evaluation of the effectiveness of night vision equipment for nighttime marine mammal observations.

presence of the seismic vessel in the area, and (b) retain the option of initiating a ramp up to full array under poor visibility conditions. In contrast, a shut down is 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 array, the number of guns operating will be reduced to a single 70 in^3 airgun. The pre-season estimates of the 190 dB (rms) and 180 dB (rms) safety radii around the power down source are 19 m and 86 m, respectively. The 70 in^3 airgun power down source will be measured during acoustic sound source measurements conducted at the start of seismic operations. If a marine mammal is detected within or near the applicable safety radius around the single 70 in^3 airgun, it too will be deactivated resulting in a complete shut down (see next subsection).

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

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

Shut down Procedures

The operating airgun(s) will be shut down completely if a marine mammal approaches or enters the then-applicable safety radius and a power down is not practical or adequate to reduce exposure to less than 190 or 180 dB (rms), as appropriate. The operating airgun(s) will also be shut down completely if a marine mammal approaches or enters the estimated safety radius around the reduced source (one 70 in^3 airgun) that will be used during a power down.

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

Ramp up Procedures

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

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

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

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

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

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.

ION developed a “Plan of Cooperation” (POC) for the proposed 2012 seismic survey in the Beaufort and Chukchi seas in consultation with representatives of Barrow, Nuiqsut, Kaktovik, and

Wainwright and subsistence users within these communities. A final draft of the POC will be delivered to NMFS and other regulatory agencies as soon as the consultation process is complete in late May or early June, 2012.

ION will continue to engage with the communities of Barrow, Nuiqsut, Kaktovik, and Wainwright to identify and avoid areas of potential conflict. The meetings with stakeholders that took place in 2010 and 2011 are listed in Table 16 and Table 17, respectively. The meetings that have taken place in 2012 as well as additional proposed meetings are listed in Table 18. Members of marine mammal co-management groups and groups that address subsistence activities were specifically notified of the public meetings so that they could provide input (Table 19). A record of all consultation with subsistence users will be included in the 2012 Final POC document.

Table 16. List of meetings and correspondence with potentially affected stakeholders and subsistence users.

Community/Stakeholder	Date	Location	Notes
NSB – Department of Wildlife Management	15 December 2009	Barrow	Met with Robert Sudam of NSB to discuss proposed project
AEWC and Village Whaling Captains	12 – 13 February 2010	Barrow	Presented the proposed project to AEWC as part of the 2010 Annual Captains' Mini-Convention
Kaktovik Leadership	16 March 2010	Anchorage	Meeting with Kaktovik mayor and president of Kaktovik Inupiat Corporation scheduled, but canceled due to illness
Nuiqsut Leadership	17 March 2010	Nuiqsut	Meeting with KSOP and Native Village of Nuiqsut. Thomas Napageak Jr., mayor of Nuiqsut was present.
NSB Planning Commission	18 March 2010	Barrow	Presented the proposed project to NSB Planning Commission. Representatives of NSB Planning Department were present.
Barrow Leadership	18 March 2010	Barrow	Meeting with NSB Dept. of Wildlife Management, ICAS, and Native Village of Barrow
NMFS Open Water Meeting	22 – 24 March 2010	Anchorage	Presented at NMFS Open Water Meeting.
NMFS Peer Review Meeting	25 March 2010	Anchorage	Presented to NMFS Peer Review Meeting
Barrow public meeting	8 April 2010	Barrow	Public meeting held at Inupiat Heritage Center from 7pm to 9pm
Kaktovik public meeting	10 April 2010	Kaktovik	Public meeting held at Kaktovik Community Center from 7pm to 9pm
Nuiqsut public meeting	17 April 2010	Nuiqsut	Public meeting held at Kisik Community Center from 7pm to 9pm
Kaktovik update	3 August 2010	Kaktovik	Public meeting held at Kaktovik Community Center from 7pm to 9pm to provide an update of the proposed project prior to beginning operations.
Nuiqsut update	4 August 2010	Nuiqsut	Public meeting held at Kisik Community Center from 7pm to 9pm to provide an update of the proposed project prior to beginning operations.
Barrow update	5 August 2010	Barrow	Public meeting held at Inupiat Heritage Center from 7pm to 9pm to provide an update of the proposed project prior to beginning operations.
NSB Planning Commission	30 September 2010	Barrow	Presented the proposed project to NSB Planning Commission. Representatives of NSB Planning Department were present.
Notice of Project Delay	30 September 2010	Barrow	Notified NSB Planning Commission, Barrow,

			Nuiqsut, and Kaktovik leadership, and subsistence users' groups that the 2010 BeaufortSPAN^{TM} West Program would be delayed a year due to technical complications with the seismic vessel.
AEWC	7-8 December 2010	Barrow	Presented the proposed project to the AEWC at their 4th Quarter Meeting

Notes:

AEWC = Alaska Eskimo Whaling Commission
ICAS = Inupiat Community of the Arctic Slope
NMFS = National Marine Fisheries Service
NSB = North Slope Borough
KSOP = Kuukpikmiut Subsistence Oversight Panel, Inc.
SAR = Search and Rescue

Table 17. 2011 Meetings and Correspondence with Potentially Affected Stakeholders and Subsistence Users

Community/Stakeholder	Date	Location	Notes
AEWC and Village Whaling Captains	18 February 2011	Barrow	Presented the proposed project to the AEWC as part of the 2011 Annual Captains' Mini-Convention.
Barrow Public Meeting	19 February	Barrow	Public meeting held at the Inupiat Heritage Center from 7pm to 9pm. Invitations to the public meeting were sent to Barrow leadership prior to the public meeting.
Nuiqsut Public Meeting	21 February 2011	Nuiqsut	Public meeting held at the Kuukpik Corporation Hotel from 7pm to 9pm. Invitations to the public meeting were sent to Nuiqsut leadership prior to the public meeting.
Kaktovik Public Meeting	22 February 2011	Kaktovik	ION attempted to host a public meeting in Kaktovik at the Kaktovik Community Center from 7pm to 9pm, but the meeting was cancelled due to weather. Invitations to the public meeting were sent to Kaktovik leadership prior to the public meeting.
NSB Planning Commission	24 February 2011	Barrow	Presented to proposed project to NSB Planning Commission. Representatives of NSB Planning Department were present.
NMFS Open Water Meeting	7-8 March 2011	Anchorage	Presented at NMFS Open Water Meeting.
NMFS Peer Review Meeting	9 March 2011	Anchorage	Presented to NMFS Peer Review Panel.
NSB Planning Commission	18 April 2011	Barrow	Submitted a letter to NSB Planning Commission members addressing questions raised at the 24 February 2011 Planning Commission meeting.
Kaktovik Leadership and Public Meeting	18 April 2011	Kaktovik	Leadership and Public meeting held at the Kaktovik Community Center from 5pm to 6pm. This was a re-schedule of the planned February meeting that was canceled due to weather.

Nuiqsut Leadership Meeting	19 April 2011	Nuiqsut	ION attempted to meet with Leadership in Nuiqsut, including KSOP, the Native Village of Nuiqsut, the City of Nuiqsut, Kuukpik Corp., and the Nuiqsut Whaling Captains' Association. The meeting was cancelled due to weather.
Barrow Leadership Meeting	20 April 2011	Barrow	ION notified Barrow leadership that they would be in Barrow this day and that ION would be happy to meet with members of Barrow leadership. Due to timing (preparation for Barrow spring whale hunt), no meetings were scheduled.
Notice of Project Delay	7 July 2011	Multiple Locations	Notified Barrow, Nuiqsut, Kaktovik, and North Slope Borough leadership via a letter that the 2011 BeaufortSPAN^{TM} West Program would be delayed a year.
AEWC 2nd Quarter Meeting	21-22 July 2012	Fairbanks	Notified AEWC Commissioners of the project delay.
Notice of Project Delay	16 August 2011	Kaktovik	ION notified leadership in Kaktovik that the 2011 BeaufortSPAN^{TM} West Program would be delayed a year.
Notice of Project Delay	17 August 2011	Barrow	ION notified leadership in Barrow that the 2011 BeaufortSPAN^{TM} West Program would be delayed a year due to uncertainty in the availability of the *Polar Explorer*.
Notice of Project Delay	18 August 2011	Nuiqsut	ION notified leadership in Nuiqsut that the 2011 BeaufortSPAN^{TM} West Program would be delayed a year.
AEWC Commissioners	12 December 2011	Barrow	Discussed 2012 Operational Plan and Conflict Avoidance Agreement

Notes:
AEWC = Alaska Eskimo Whaling Commission
NMFS = National Marine Fisheries Service
KSOP = Kuukpikmiut Subsistence Oversight Panel, Inc.

Table 18. 2012 Meetings and Correspondence with Potentially Affected Stakeholders and Subsistence Users

Community/Stakeholder	**Date**	**Location**	**Notes**
Kaktovic Public Meeting	23 January 2012	Kaktovik	Review of proposed project for 2012
Nuiqsut Public Meeting	24 January 2012	Nuiqsut	Canceled due to weather, rescheduled for a later date
Barrow Public Meeting	25 January 2012	Barrow	Review of proposed project for 2012
Barrow Whaling Captains Association	25 January 2012	Barrow	Review of proposed project for 2012
Wainwright Whaling Captains Association	26 January 2012	Wainwright	Canceled due to weather, rescheduled for a later date
2012 AEWC CAA Meeting	16-17 February 2012	Barrow	Review of proposed 2012 project, CAA language comments
2012 NMFS Open Water Meeting	6-8 March 2012	Anchorage	Review of proposed project for 2012
Barrow Update	August 2012 (proposed)	Barrow	ION will provide an update of the proposed project prior to

			beginning operations.
Nuiqsut Update	August 2012 (proposed)	Nuiqsut	ION will provide an update of the proposed project prior to beginning operations.
Kaktovik Update	August 2012 (proposed)	Kaktovik	ION will provide an update of the proposed project prior to beginning operations.

Table 19. List of co-management groups and groups that address subsistence activities.

Subsistence and Community Groups	
Alaska Eskimo Whaling Commission Alaska Ice Seal Committee Alaska Nanuuq Commission Alaska Beluga Whale Committee Eskimo Walrus Committee Kuukpikmiut Subsistence Oversight Panel, Inc.	Inupiat Community of the Arctic Slope Native Village of Nuiqsut Native Village of Barrow Native Village of Kaktovik

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...

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

ION’s vessel-based monitoring program is designed to meet the requirements of the Incidental Harassment Authorization (IHA) and Letter of Authorization (LOA) requested from NMFS and USFWS, respectively, as well as to meet any other agreements between ION and other agencies or groups. The objectives of the program will be:

- to ensure that disturbance to marine mammals and subsistence hunts is minimized and all permit stipulations are followed,
- to document the effects of the proposed survey activities on marine mammals, and
- to collect baseline data on the occurrence and distribution of marine mammals in the survey area.

This monitoring plan will be implemented by a team of experienced MMOs. MMOs will be stationed aboard the source vessel and icebreaker throughout the duration of the seismic survey. Reporting of the results of the vessel-based monitoring program will include the estimation of the number of “takes” as stipulated in the IHA and LOA.

The vessel-based monitoring will provide:

- the basis for real-time mitigation, if necessary, as required by the various permits that ION receives,
- information needed to estimate the number of "takes" of marine mammals by harassment, which must be reported to NMFS and USFWS,
- data on the occurrence, distribution, and activities of marine mammals in the areas where the survey program is conducted,
- information to compare the distances, distributions, behavior, and movements of marine mammals relative to the survey vessel at times with and without airgun activity, and
- a communication channel to coastal communities including Inupiat whalers.

ION's vessel-based monitoring program will be operated and administered consistent with other monitoring programs conducted during seismic surveys in the Arctic or such alternative requirements as may be specified in the IHA or LoA issued by NMFS and USFWS, respectively. Any other agreements between ION and agencies or groups such as MMS, the North Slope Borough (NSB), and the Alaska Eskimo Whaling Commission (AEWC) will also be fully incorporated into the monitoring plan. All MMOs will be provided training as described below. At least one Inupiat knowledgeable about the mammals of the area is expected to be included as a member of the MMO team and will have the additional responsibility of communicating with coastal communities and directly with Inupiat whalers during the whaling season, should it be necessary. Details of the vessel-based monitoring program are described below.

Marine Mammal Observers

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

Number of Observers

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

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

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

Observer Qualifications and Training

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

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

Biologist observers and Inupiat observers will also complete a two or three-day training and refresher session together on marine mammal monitoring, to be conducted shortly before the anticipated start of the seismic survey. When possible, experienced observers will be paired with inexperienced observers. The training session(s) will be conducted by qualified marine mammalogists with extensive crew-leader experience during previous vessel-based seismic monitoring programs.

Primary objectives of the training include:

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

MMO Handbook

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

- summary of the project, marine mammals and underwater noise, the monitoring program, the NMFS IHA and USFWS LOA and other regulations/permits/agencies, the Marine Mammal Protection Act;
- monitoring and mitigation objectives and procedures, initial safety radii;
- responsibilities of staff and crew regarding the marine mammal monitoring plan;

- instructions for ship crew regarding the marine mammal monitoring plan;
- data recording procedures: codes and coding instructions, common coding mistakes, electronic database; navigational, marine physical, field data sheet;
- use of specialized field equipment (reticle binoculars, NVDs, FLIR cameras, laser rangefinders);
- reticle binocular distance scale;
- table of wind speed, Beaufort wind force, and sea state codes;
- data storage and backup procedures;
- list of species that might be encountered: identification, natural history;
- safety precautions while onboard;
- crew and/or personnel discord; conflict resolution among MMOs and crew;
- drug and alcohol policy and testing;
- scheduling of cruises and watches;
- communications;
- list of field gear that will be provided;
- suggested list of personal items to pack;
- suggested literature, or literature cited; and
- copies of the NMFS IHA and USFWS LOA when available.

Monitoring Methodology

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

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

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

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

Distances to nearby marine mammals will be estimated with binoculars (Fujinon 7 × 50 binoculars) containing a reticle to measure the vertical angle of the line of sight to the animal relative to the horizon. Observers may use a laser rangefinder to test and improve their abilities for visually estimating distances to objects in the water. However, previous experience has shown that a Class 1 eye-safe device was not able to measure distances to seals more than about 70 m (230 ft) away. The device was very useful in improving the distance estimation abilities of the observers at distances up to about 600 m (1968 ft)—the maximum range at which the device could measure distances to highly reflective objects such as other vessels. Humans observing objects of more-or-less known size via a standard observation protocol, in this case from a standard height above water, quickly become able to estimate distances within about ±20% when given immediate feedback about actual distances during training.

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

Monitoring At Night and In Poor Visibility

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

Additional details regarding the monitoring protocol during NVD and FLIR system use has been developed in order to collect data in a standardized manner such that the effectiveness of the two devices can be analyzed and compared. Details of the protocol are included in the monitoring plan document that accompanies this application.

Specialized Field Equipment

ION will provide or arrange for the following specialized field equipment for use by the onboard MMOs: 7×50 reticle binoculars, Big-eye binoculars or high power image-stabilized binoculars, GPS unit, laptop computers, night vision binoculars, digital still and possibly digital video cameras in addition to the aforementioned FLIR camera system.

Field Data-Recording, Verification, Handling, and Security

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

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

Reporting

Field Reports

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

90-Day Report

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

The technical report(s) will include:

- summaries of monitoring effort: total hours, total distances, and distribution of marine mammals through the study period accounting for sea state and other factors affecting visibility and detectability of marine mammals;
- methods, results, and interpretation pertaining to all acoustic characterization work and vessel-based monitoring;
- analyses of the effects of various factors influencing detectability of marine mammals including sea state, number of observers, and fog/glare;
- species composition, occurrence, and distribution of marine mammal sightings including date, water depth, numbers, age/size/gender categories, group sizes, and ice cover;
- analyses of the effects of survey operations:
  - sighting rates of marine mammals during periods with and without airgun activities (and other variables that could affect detectability);
  - initial sighting distances versus airgun activity state;
  - closest point of approach versus airgun activity state;
  - observed behaviors and types of movements versus airgun activity state;
  - numbers of sightings/individuals seen versus airgun activity state;
  - distribution around the survey vessel versus airgun activity state;
  - estimates of "take by harassment".

Acoustic Monitoring Plan

Sound Source Measurements

As described above, received sound levels were modeled for the full 26 airgun, 4450 in^3 array in relation to distance and direction from the source (Zykov et al. 2010). These modeled distances will be used as temporary safety radii until measurements of the airgun sound source are conducted. The measurements will be made at the beginning of the field season and the measured radii used for the remainder of the survey period. An acoustics contractor with experience in the Arctic conducting similar measurements in recent years will use their equipment to record and analyze the underwater sounds and write the summary reports as described below.

The objectives of the sound source measurements planned for 2012 in the Beaufort Sea will be (1) to measure the distances in potentially ice covered waters in the broadside and endfire directions at which broadband received levels reach 190, 180, 170, 160, and 120 dB (rms) re 1 μPa for the energy source array combinations that may be used during the survey activities, and (2) measure the sounds produced by the icebreaker and seismic vessel as they travel through sea ice. Conducting the sound source and vessel measurements in ice-covered waters using bottom founded recorders creates a risk of not being able to retrieve the recorders and analyze the data until the following year. If the acoustic recorders are not deployed or are unable to be recovered because of too much sea ice, Ion will use measurements of the same airgun source taken in the Canadian Beaufort Sea in 2010, along with sound velocity measurements taken in the Alaskan Beaufort Sea at the start of the 2012 survey to update the propagation model and estimate new safety zones. These modeled results will then be used for mitigation purposes during the remainder of the survey.

The airgun configurations measured will include at least the full 26 airgun array and the single 70 in^3 mitigation airgun that will be used during power downs. The measurements of airgun array sounds will be made by an acoustics contractor at the beginning of the survey and the distances to the various radii will be reported as soon as possible after recovery of the equipment. The primary radii of concern will be the 190 and 180 dB safety radii for pinnipeds and cetaceans, respectively, and the 160 dB disturbance radii. In addition to reporting the radii of specific regulatory concern, nominal distances to other sound isopleths down to 120 dB (rms) will be reported in increments of 10 dB.

Data will be previewed in the field immediately after download from the hydrophone instruments. An initial sound source analysis will be supplied to NMFS, USFWS, and the airgun operators within 120 hours of completion of the measurements. The report will indicate the distances to sound levels based on fits of empirical transmission loss formulae to data in the endfire and broadside directions. A more detailed report will be issued to NMFS and USFWS as part of the 90-day report following completion of the acoustic program.

Seismic Hydrophone Streamer Recording of Vessel Sounds

Although some measurements of icebreaking sounds have previously been reported, acoustic data on vessels traveling through relatively light ice conditions, as will be the case during the proposed survey, are not available. In order to gather additional information on the sounds produced by this type of icebreaking, Ion proposes to use the hydrophones in the seismic streamer on a routine basis throughout the survey. Once every hour the airguns will not be fired at 2 consecutive intervals (one seismic pulse interval is typically ~18 seconds, so there will be ~54 seconds between seismic pulses at this time) and instead a period of background sounds will be recorded, including the sounds generated by the vessels. Over the course of the survey this should generate as many as 750 records of vessel sounds traveling through various ice conditions (from open water to 100% cover juvenile first year ice or lighter multi-year ice). The acoustic data during each sampling period from each hydrophone along the 9 km streamer will be analyzed and used to estimate the propagation loss of the vessel sounds. The acoustic data received from the hydrophone streamer will be recorded at an effective bandwidth of 0–400 Hz. In order to estimate sound energy over a larger range of frequencies (broadband), results from previous measurements of icebreakers could be generalized and added to the data collected during this project.

Over-winter Acoustic Recorders

In order to collected additional data on the propagation of sounds produced by icebreaking and seismic airguns in ice-covered waters, as well as on vocalizing marine mammals, Ion intends to collaborate with other Industry operators to deploy acoustics recorders in the Alaskan Beaufort Sea in fall of 2012, to be retrieved during the 2013 open-water season.

During winter 2011–2012 AURAL acoustic recorders were deployed at or near each of the 5 acoustic array sites established by Shell for monitoring the fall bowhead whale migration through the

Beaufort Sea, as well as one site near the shelf break in the central Alaskan Beaufort Sea (Fig. 4). These recorders will be retrieved in July of 2012 when Shell deploys DASARs at the 5 array locations. When the DASAR arrays are retrieved in early October Ion intends to coordinate with Shell to re-deploy the 6 AURAL recorders to the same locations used during the 2011–2012 winter. Redeploying the recorders in the same locations will provide comparable data from a year with little to no offshore industrial activity (2011) to a year with more offshore industrial activity (2012). Acoustic data from the over-winter recorders will be analyzed to address the following objectives:

1. Characterize the sounds and propagation distances produced by Ion’s source vessel, icebreaker, and airguns on and to the edge of the U.S. Beaufort Sea shelf,
2. Characterize ambient sounds and marine mammal calls during October and November to assess the relative effect of Ion’s seismic survey on the background conditions, and to characterize marine mammal calling behavior, and
3. Characterize ambient sound and enumerate marine mammal calls through acoustic sampling of the environment form December 2012 through July 2013, when little or no anthropogenic sounds are expected.

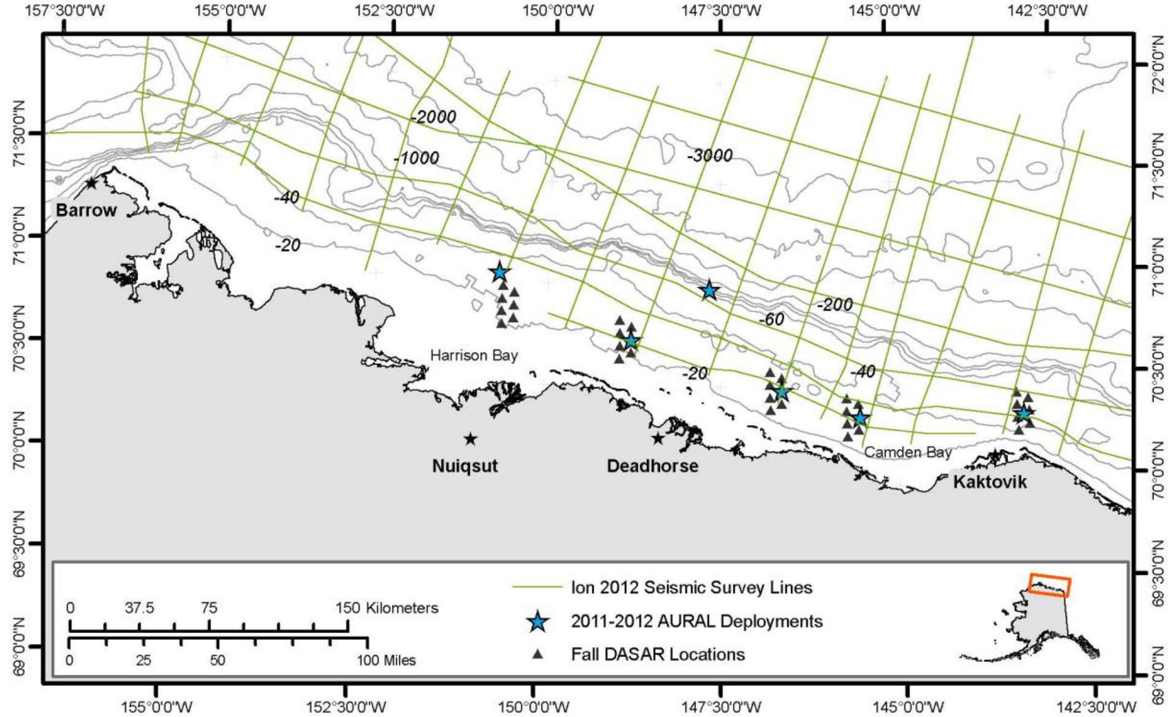

FIGURE 4. Map showing locations of AURAL acoustic recorders deployed overwinter 2011-2012 by Shell. Ion will coordinate with Shell to re-deploy the recorders in approximately the same locations for the 2012–2013 winter.

XIV. COORDINATING RESEARCH TO REDUCE AND EVALUATE INCIDENTAL TAKE

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

ION will coordinate the planned marine mammal monitoring program associated with the seismic survey in the Beaufort and Chukchi seas with other parties that may have interest in this area and/or be conducting marine mammal studies in the same region during operations. No other marine mammal studies are expected to occur in the survey area at the proposed time.

ION has coordinated, and will continue to coordinate, with other applicable Federal, State and Borough agencies, and will comply with their requirements.

- ION and LGL have had contact with USFWS biologists at the Office of Marine Mammal Management, Anchorage, 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".
- ION has met with the NSB Department of Wildlife Management concerning marine mammal and fisheries issues during the planning phases of this project.
- ION has communicated with representatives of subsistence hunters in Barrow, Nuiqsut, and Kaktovik with regard to potential concerns about interactions with subsistence hunting and negotiation of a "Plan of Cooperation."

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

ADFG (Alaska Department of Fish and Game). 2010. Satellite Tracking of Western Arctic Bowhead Whales. Preliminary reports and summaries available at:

http://www.wildlife.alaska.gov/index.cfm?adfg=marinemammals.bowhead

Allen, B.M., and R.P. Angliss. 2011. Alaska Marine Mammal Stock Assessments, 2010. NOAA Technical Memorandum NMFS-AFSC-223, 292 p.

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. 1993. Human disturbances of denning polar bears in Alaska. Arctic 46(3):246-250.

Amstrup, S. C., and C. L. Gardner. 1994. Polar bear maternity denning in the Beaufort Sea. Journal of Wildlife Management 58(1):1-10.

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

Au, W.W.L., D.A. Carder, R.H. Penner and B.L. Scronce. 1985. Demonstration of adaptation in beluga whale echolocation signals. **J. Acoust. Soc. Am.** 77(2):726-730.

Au, W.W.L., R.H. Penner and C.W. Turl. 1987. Propagation of beluga echolocation signals**. J. Acoust. Soc. Am.** 82(3):807-813.

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

Bain, D.E. and R. Williams. 2006. Long-range effects of airgun noise on marine mammals: responses as a function of received sound level and distance. Paper SC/58/E35 presented to the IWC Scient. Commit., IWC Annu. Meet., 1-13 June, St. Kitts.

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. and T. Gerrodette. 1996. Abundance of cetaceans in California waters based on 1991 and 1993 ship surveys. NOAA Technical Memorandum NOAA-TM-NMFS-SWFSC-233. La Jolla, CA. 15 pp.

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.

Bengtson, J.L., L. M. Hiruki-Raring, M. A. Simpkins, and P. L. Boveng. 2005. Ringed and bearded seal densities in the eastern Chukchi Sea, 1999-2000. **Polar Biol.** 28:833-845-230.

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.

Blackwell, S.B., C.R. Greene, Jr., T.L. McDonald, M.W. McLennan, C.S. Nations, R.G. Norman, and A. Thode. 2008. Beaufort Sea acoustic monitoring program. Chapter 8 *In* Funk, D.W., R. Rodrigues, D.S. Ireland, and W.R. Koski (eds.). Joint monitoring program in the Chukchi and Beaufort seas, July–November 2007. LGL Alaska Report P971-2. Report from LGL Alaska Research Associates, Inc., Anchorage, Ak, LGL Ltd., environmental research associates, King City, Ont., JASCO Research, Victoria, B.C., and Greeneridge Sciences, Inc., Goleta, CA, for Shell Offshore, Inc., ConocoPhillips Alaska, Inc., and National Marine Fisheries Service, and U.S. Fish and Wildlife Service.

Blackwell, S.B., C.R. Greene, T.L. McDonald, M.W. McLennan, C.S. Nations, R.G. Norman, and A. Thode. 2009a. Beaufort Sea bowhead whale migration route study. (Chapter 8) In: Ireland, D.S., D.W. Funk. R. Rodrigues, and W.R. Koski (eds.). 2009. Joint Monitoring Program in the Chukchi and Beaufort seas, open water seasons, 2006–2007. LGL Alaska Report P971–2, Report from LGL Alaska Research Associates, Inc., Anchorage, AK, LGL Ltd., environmental research associates, King City, Ont., JASCO Research, Ltd., Victoria, BC, and Greeneridge Sciences, Inc., Santa Barbara, CA, for Shell Offshore, Inc., Anchorage, AK, ConocoPhillips Alaska, Inc., Anchorage, AK, and the National Marine Fisheries Service, Silver Springs, MD, and the U.S. Fish and Wildlife Service, Anchorage, AK. 485 p. plus Appendices.

Blackwell, S.B., C.S. Nations, T.L. McDonald, A.M. Thode, K.H. Kim, C.R. Greene, and M.A. Macrander. 2009b. Effects of seismic exploration activities on the calling behavior of bowhead whales in the Alaskan Beaufort Sea. p. 35 In: Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Canada, 12-16 Oct. 2009. 306 p.

Blix, A.S. and J.W. Lentfer. 1992. Noise and vibration levels in artificial polar bear dens as related to selected petroleum exploration and development activities. **Arctic** 45(1):20-24.

Bluhm, B.A., K.O. Coyle, B. Konar and R. Highsmith. 2007. High gray whale relative abundances associated with an oceanographic front in the south-central Chukchi Sea. **Deep-sea Research II** 54:2919-2933.

Bluhm, B.A. and R. Gradinger. 2008. Regional variability in food availability for arctic marine mammals. **Ecological Applications** 18:77-96.

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.

Braund, S.R., and J. Kruse. 2009. Synthesis: Three decades of research on socioeconomic effects related to offshore petroleum development in coastal Alaska. MMS OCS Study 2009-006.

Brewer, K.D., M.L. Gallagher, P.R. Regos, P.E. Isert, and J.D. Hall. 1993. Kuvlum #1 exploration prospect final report – site specific monitoring program. Report from Coastal & Offshore Pacific Corporation, Walnut Creek, CA, for ARCO Alaska. Inc.

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., F.R. Christian, V.D. Moulton, B. Mactavish, and S. Fufault. 2004. 2004 Laurentian 2-D seismic curvey environemtal assessment. Report prepared by LGL Limited, St. John’s NL, and Canning & Pitt Associates, Inc., St. John’s, NL, for ConocoPhillips Canada Resources Corporation, Calgary, AB. 274 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. 1981a. Ribbon seal—*Phoca fasciata*. Page 89-109 In S. H. Ridgway and R. J. Harrison (eds.), Handbook of marine mammals. Vol. 2. Seals. Academic Press, New York

Burns, J.J. 1981b. 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., L.H. Shapiro, and F.H. Fay. 1981. Ice as marine mammal habitat in the Bering Sea. Pages. 781-797 *In* D.W. Hood and J.A. Calder (eds.), The eastern Bering Sea shelf: oceanography and resources. Vol. 2. U.S. Dep. Commer., NOAA, Off. Mar. Pollut. Assess., Juneau, Alaska.

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.

Cameron, M. and P. Boveng. 2009. Habitat Use and Seasonal Movements of Adult and Sub-Adult Bearded Seals. AFSC Quarterly Report, October November December 2009.

Cameron, M., P. Boveng, J. Goodwin, A. Whiting. 2009. Seasonal movements, habitat selection, foraging and haul-out behavior of adult bearded seals. Poster Presentation: Bio. of Mar. Mam. 18th Biennial Conf., Soc.for Mar. Mamm., Quebec City, Canada, Oct 2009.

CBD. 2007. Petition to list the ribbon seal (*Histriophoca fasciata*) as a threatned or endangered species under the Endangered Species Act. Center for Biological Diversity, San Francisco CA.

CBD. 2008. Petition to list three seal species under the Endangered Species Act: ringed seal (*Pusa hispica*), bearded seal (*Erignatha barbatus*), and spotted seal (*Phoca largha*). Center for Biological Diversity, San Francisco CA.

Christie, K., C. Lyons, and W.R. Koski. 2010. Beaufort Sea aerial monitoring program. (Chapter 7) In: Funk, D.W., D.S. Ireland, R. Rodrigues, and W.R. Koski (eds.). 2010. Joint Monitoring Program in the Chukchi and Beaufort seas, open water seasons, 2006–2008. LGL Alaska Report P1050-3, Report from LGL Alaska Research Associates, Inc., LGL Ltd., Greeneridge Sciences, Inc., and JASCO Research , Ltd., for Shell Offshore, Inc. and Other Industry Contributors, and National Marine Fisheries Service, U.S. Fish and Wildlife Service. 499 p. plus Appendices.

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., S. Moore, and D. Ljungblad. 1989. Observations of the gray whale (*Eschrichtius robustus*) utilization and patterns in the northeast Chukchi Sea, July-October 1982-1987. **Can. J. Zool**. 67:2646-2653.

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.

Clarke, J.T., C.L Christman, S.L. Grassia, A.A. Brower, and M.C. Ferguson. 2011a. Aerial Surveys of Endangered Whales in the Beaufort Sea, Fall 2009. Final Report, OCS Study BOEMRE 2010-040. National Marine Mammal Laboratory, Alaska Fisheries Science Center, NMFS, NOAA, 7600 Sand Point Way NE, F/AKC3, Seattle, WA 98115-6349.

Clarke, J.T., M.C. Ferguson, C.L. Christman, S.L. Grassia, A.A. Brower, and L.J. Morse. 2011b. Chukchi Offshore Monitoring in Drilling Area (COMIDA) Distribution and Relative Abundance of Marine Mammals: Aerial Surveys. Final Report, OCS Study BOEMRE 2011-06. National Marine Mammal Laboratory, Alaska Fisheries Science Center, NMFS, NOAA, 7600 Sand Point Way NE, F/AKC3, Seattle, WA 98115-6349.

COMIDA. 2009. Chukchi Offshore Monitoring in Drilling Area. National Marine Mammal Laboratory Cetacean Assessment and Ecology Program, Bowhead Whale Aerial Surveys: Preliminary Data. Available at: http://www.afsc.noaa.gov/NMML/cetacean/bwasp/flights_COMIDA_fy09.php

Coyle, K.O., B. Bluhm, B. Konar, A. Blanchard and R.C. Highsmith. 2007. Amphipod prey of gray whales in the northern Bering Sea: Comparison of biomass and distribution between the 1980s and 2002-3. **Deep-sea Research II** 54:2906-2918.

Craig, P.C. 1984. Fish use of coastal waters of the Alaskan Beaufort Sea: A review. **Transactions of the American Fisheries Society** 113:265-282.

Crawford, R.E. 2010. Occurrence of Arctic cod shoals along the Chukchi and Beaufort continental slope regions. 2010 Alaska Marine Science Symposium, Anchorage, Alaska.

Cummings, W.C. and D.V. Holiday. 1883. Prelminary measurement of sound attenuation by snow over a model seal lair. **J. Acoust. Soc. Am.** 74(suppl. 1):S55.

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.

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

Di Iorio, L. and C.W. Clark. 2009. Exposure to seismic survey alters blue whale acoustic communication. Biol. Lett. doi: 10.1098/rsbl.2009.0651.

Erbe, C, and D.M. Farmer. 1998. Masked hearing thresholds of a beluga whale (*Delphinapterus leucas*) in icebreaker noise. **Deep-Sea Research II**. 45:1373-1388.

Erbe, C. and D.M. Farmer. 2000. Zones of impact around icebreakers affecting beluga whales in the Beaufort Sea. **J. Acoust. Soc. Am.** 108 (3):1332-1340.

Ferguson, M., NOAA–National Marine Mammal Lab. Personal Communication. 2011. E-mail communication via Shane Guan, NOAA–Office of Protected Resources.

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., 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.

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. 1993. Assessment of injury to harbor seals in Prince William Sound, Alaska, and adjacent areas following the *Exxon Valdez* oil spill. State-Federal Natural Resource Damage Assessment, Marine Mammals Study No. 5. 95 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.

Frost, K.J., L.F. Lowry, G. Pendleton, and H.R. Nute. 2004. Factors affecting the observed densities of ringed seals, *Phoca hispida*, in the Alaskan Beaufort Sea, 1996-99. **Arctic** 57(2):115-128.

Fuller, A.S. and J.C. George. 1997. 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.

Funk, D., D Hannay, D. Ireland, R. Rodrigues, W. Koski. (eds.) 2008. Marine mammal monitoring and mitigation during open water seismic exploration by Shell Offshore Inc. in the Chukchi and Beaufort Seas, July–November 2007: 90-day report. LGL Rep. P969-1. Rep. from LGL Alaska Research Associates Inc., LGL Ltd., and JASCO Research Ltd. for Shell Offshore Inc, Nat. Mar. Fish. Serv., and U.S. Fish and Wild. Serv. 218 pp plus appendices.

Funk, D.W., D.S. Ireland, R. Rodrigues, and W.R. Koski (eds.). 2010. Joint Monitoring Program in the Chukchi and Beaufort seas, open water seasons, 2006–2008. LGL Alaska Report P1050-3, Report from LGL Alaska Research Associates, Inc., LGL Ltd., Greeneridge Sciences, Inc., and JASCO Research , Ltd., for Shell

Offshore, Inc. and Other Industry Contributors, and National Marine Fisheries Service, U.S. Fish and Wildlife Service. 499 p. plus Appendices.

Funk., D.W., D.S. Ireland, R. Rodrigues, and W.R. Koski (eds.). 2010. Draft Final Report: Joint Monitoring Program in the Chukchi and Beaufort seas, open water seasons, 2006–2008. LGL Alaska Report P1050-2, Report from LGL Alaska Research Associates, Inc., LGL Ltd., Greeneridge Sciences, Inc., and JASCO Research , Ltd., for Shell Offshore, Inc. and Other Industry Contributors, and National Marine Fisheries Service, U.S. Fish and Wildlife Service. 506 p. plus Appendices.

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

Galginaitis, M. and D.W. Funk. 2004. Annual assessment of subsistence bowhead whaling near Cross Island, 2001 and 2002: ANIMIDA Task 4 final report. OCS Study MMS 2004-030. Rep. from Applied Sociocultural Res. and LGL Alaska Res. Assoc. Inc., Anchorage, AK, for U.S. Minerals Manage. Serv., Anchorage, AK. 55 p. + CD-ROM.

Galginaitis, M. and D.W. Funk. 2005. Annual assessment of subsistence bowhead whaling near Cross Island, 2003: ANIMIDA Task 4 annual report. OCS Study MMS 2005-025. Rep. from Applied Sociocultural Research and LGL Alaska Res. Assoc. Inc., Anchorage, AK, for U.S. Minerals Manage. Serv., Anchorage, AK. 36 p. + Appendices.

Galginaitis, M.S. and W.R. Koski. 2002. Kaktovikmiut whaling: historical harvest and local knowledge of whale feeding behavior. p. 2-1 to 2-30 (Chap. 2*) 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.

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.

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., L.M. Philo, K. Hazard, D. Withrow, G.M. Carroll, and R. Suydam. 1994. Frequency of killer whale (*Orcincus orca*) attacks and ship collisions based on scarring on bowhead whales (*Balaena mysticetus*) of the Bering-Chukchi-Beaufort Seas stock. **Arctic** 47(3):247-255

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.

Gjertz, I., K.M. Kovacs, C. Lydersen, and Ø. Wiig. 2000. Movements and diving of adult ringed seals (*Phoca hispida*) in Svalbard. **Polar Biol.** 23:651-656.

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.

Green, G.A., K. Hashagen, and D. Lee. 2007. Marine mammal monitoring program, FEX barging project, 2007. Report prepared by Tetra Tech EC, Inc., Bothell WA, for FEX L.P., Anchorage, AK.

Greene, C.R. 1987. Acoustic studies of underwater noise and localization of whale calls. (Chap. 2, 128 p.) *In*: LGL and Greeneridge (1987), Responses of bowhead whales to an offshore drilling operation in the Alaskan Beaufort Sea, autumn 1986. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for Shell Western E & P Inc., Anchorage, AK. 371 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.

Greene, C.R., Jr., R.G. Norman, S.B. Blackwell, and A. Thode. 2007. Acoustics research for studying bowhead migration, 2006. Chapter 10 *In* D.S. Ireland, D.W. Funk, R. Rodrigues, and W.R. Koski (eds.). Joint monitoring program in the Chukchi and Beaufort seas, July-November 2006. LGL Rep. P891-2. Prepared by LGL Alaska Research Associates, Inc., Anchorage, AK, and LGL Ltd., environmental research associates, King City, Ont., for Shell Offshore Inc., ConocoPhillips Alaska, Inc., GX Technology, the National Marine Fisheries Service, and the U.S. Fish and Wildlife Service.

Haley, B. 2006. Marine mammal monitoring during University of Texas at Austin's marine geophysical survey of the western Canada Basin, Chukchi Borderland and Mendeleev Ridge, Arctic Ocean, July–August 2006. Report from LGL Alaska Research Associates, Inc., Anchorage AK, and LGL Ltd., King City, Ont., for the University of Texas at Austin, the Nat. Mar. Fish. Serv., Silver Springs, MD, and the U.S. Fish and Wildl. Serv., Anchorage, AK.

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.

Haley, B., J. Beland, D.S. Ireland, R. Rodrigues, and D.M. Savarese. 2010. Chukchi Sea vessel-based monitoring program. (Chapter 3) In: Funk, D.W, D.S. Ireland, R. Rodrigues, and W.R. Koski (eds.). 2010. Joint Monitoring Program in the Chukchi and Beaufort seas, open water seasons, 2006–2008. LGL Alaska Report P1050-3, Report from LGL Alaska Research Associates, Inc., LGL Ltd., Greeneridge Sciences, Inc., and JASCO Research , Ltd., for Shell Offshore, Inc. and Other Industry Contributors, and National Marine Fisheries Service, U.S. Fish and Wildlife Service. 499 p. plus Appendices.

Hall, J.D., M.L. Gallagher, K.D. Brewer, P.R. Regos and P.E. Isert. 1994. 1993 Kuvlum exploration area site specific monitoring program – final report. Report from Coastal & Offshore Pacific Corporation, Walnut Creek, CA, for ARCO Alaska, Inc.

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.

Hartin K.G., L.N. Bisson, S.A. Case, D.S. Ireland, and D. Hannay. (eds.) 2011. Marine mammal monitoring and mitigation during site clearance and geotechnical surveys by Statoil USA E&P Inc. in the Chukchi Sea, August–October 2011: 90-day report. LGL Rep. P1193. Rep. from LGL Alaska Research Associates Inc., LGL Ltd., and JASCO Research Ltd. for Statoil USA E&P Inc., Nat. Mar. Fish. Serv., and U.S. Fish and Wild. Serv. 202 pp, plus appendices.

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 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.

Hildebrand, J.A. 2005. Impacts of anthropogenic sound. p. 101-124 *In:* J.E. Reynolds, W.F. Perrin, R.R. Reeves, S. Montgomery, and T. Ragen (eds.), Marine Mammal Research: Conservation Beyond Crisis. Johns Hopkins Univ. Press, Baltimore, MD. 223 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.

Hubbs, C.L. and A.B. Rechnitzer. 1952. Report on experiments designed to determine effects of underwater explosions on fish life. **Calif. Fish & Game** 38(3):333-366.

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

Innes, S., M.P. Heide-Jørgensen, J. Laake, K. Laidre, H. Cleator and P. Richard. 2002. Surveys of belugas and narwhals in the Canadian high Arctic in 1996. **NAMMCO Sci. Publ.** 4:169-190.

Ireland, D., W.R. Koski, T.A. Thomas, M. Jankowski, D.W. funk, and A.M. Macrander. 2008. Distribution and relative abundance of cetaceans in the eastern Chukchi Sea in 2006 and 2007. *Rep. Int. Whal. Comm*. SC/60/BRG27.

Ireland, D.S., D.W. Funk, R. Rodrigues, and W.R. Koski (eds.). 2009. Joint Monitoring Program in the Chukchi and Beaufort seas, July-November 2007. LGL Alaska Report P971-2. Report from LGL Alaska Research Associates, Inc., Anchorage, AK, LGL Ltd., environmental research associates, King City, Ont., JASCO Research, Ltd., Victoria, BC, and Greeneridge Sciences, Inc., Santa Barbara, CA, for Shell Offshore, Inc., Anchorage, AK, ConocoPhillips Alaska, Inc., Anchorage, AK, the National Marine Fisheries Service, Silver Springs, MD, and the U.S. Fish and Wildlife Service, Anchorage, AK. 445 p. plus appendices.

IUCN (The World Conservation Union). 2008. 2008 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).

Jankowsik, M., M. Fitzgerald, B. Haley, and H. Patterson. 2008. Beaufort sea vessel-based monitoring program. Chapter 6 *In* Funk, D.W., R. Rodrigues, D.S. Ireland, and W.R. Koski (eds.). Joint monitoring program in the Chukchi and Beaufort seas, July–November 2007. LGL Alaska Report P971-2. Report from LGL Alaska Research Associates, Inc., Anchorage, Ak, LGL Ltd., environmental research associates, King City, Ont., JASCO Research, Victoria, B.C., and Greeneridge Sciences, Inc., Goleta, CA, for Shell Offshore, Inc., ConocoPhillips Alaska, Inc., and National Marine Fisheries Service, and U.S. Fish and Wildlife Service.

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, C.S., M.W. McManus and D. Skaar. 1989. Masked tonal hearing thresholds in the beluga whale. **J. Acoust. Soc. Am.** 85(6):2651-2654.

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.

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.

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

Jonsgård, Å. 1966a. The distribution of Balaenopteridae in the North Atlantic Ocean. p. 114-124 *In*: K.S. Norris (ed.), Whales, dolphins, and porpoises. Univ. Calif. Press, Berkeley and Los Angeles, CA.

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

Kaleak, J. 1996. History of whaling by Kaktovik village. p. 69-71 *In:* Proc. 1995 Arctic Synthesis Meeting, Anchorage, AK, Oct. 1995. OCS Study MMS 95-0065. U.S. Minerals Manage. Serv.,, Anchorage, AK. 206 p. + Appendices.

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.

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, Pt. 1):2173-2182.

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.

Koski, W.R., J. Mocklin, A.R. Davis, J. Zeh, D.J. Rugh, J.C. George, and R. Suydam. 2009. Preliminary estimates of 2003-2004 Bering-Chukchi-Beaufort bowhead whale (*Balaena mysticetes*) abundance from photo-identification data. Paper SC/60/BRG18 presented to the IWC SC, May 2009. 7pp.

Koski, W.R., J.C. George, G. Sheffield and M.S. Galginaitis. 2005. Subsistence harvests of bowhead whales (*Balaena mysticetus*) at Kaktovik, Alaska (1973-2000). **J. Cetac. Res. Manage**. 7(1):33-37.

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

Leatherwood, S., R.R. Reeves, W.F. Perrin, and W.E. Evans. 1982. Whales, dolphins, and porpoises of the eastern North Pacific and adjacent Arctic waters: A guide to their identification. U.S. Dept. of Commerce, NOAA Tech. Rep., NMFS Circular 444.

Leatherwood, S., A.E. Bowles, and R. Reeves. 1986. Aerial surveys of marine mammals in the southeastern Bering Sea. U.S. Department of Commerce, NOAA, OCSEAP Final Report 42:147-490.

Lentfer, J. W. and R. J. Hensel. 1980. Alaskan polar bear denning. International Conference on Bear Research and Management 4:101-8.

Le Prell, C.G. in press. Noise-induced hearing loss: from animal models to human trials. *In*: A.N. Popper and A.D. Hawkins (eds.), Effects of noise on aquatic life. Springer.

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.

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.

Long, F., Jr. 1996. History of subsistence whaling by Nuiqsut. p. 73-76 *In:* Proc. 1995 Arctic Synthesis Meeting, Anchorage, AK, Oct. 1995. OCS Study MMS 95-0065. U.S. Minerals Manage. Serv., Anchorage, AK. 206 p. + Appendices.

Lowry, L.F., K.J. Frost, and J.J. Burns. 1980. Variability of the diet of ringed seals, *Phoca hispida*, in Alaska. **Can. J. Fish Aquat. Sci.** 37:2254-2261.

Lowry, L.F., R.R. Nelson, and K.J. Frost. 1987. Observations of killer whales, (*Orcincus orca*) in western Alaska: Sightings, strandings and predation on other marine mammals. Canadian Field-Naturalist 101:6-12.

Lowry, L.F., K.J. Frost, R. Davis, R.S. Suydam and D.P. DeMaster. 1994. Satellite-tagging of spotted seals (Phoca largha) at Kasegaluk Lagoon, Alaska, 1992-1993. OCS Study MMS 94-0067. Rep. from Alaska Dep. Fish & Game, Fairbanks, AK, for U.S. Minerals Manage. Serv., Anchorage, AK. 23 p.

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.

Lowry, L.F., G. Sheffield and J.C. George. 2004. Bowhead whale feeding in the Alaskan Beaufort Sea, based on stomach contents analyses**. J. Cetac. Res. Manage.** 6(3):215-223.

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.

Lyons, C., W. Koski, and D. Ireland. 2009. Chapter 7 *In* Ireland, D.S., D.W. Funk, R. Rodrigues, and W.R. Koski (eds.). 2009. Joint monitoring program in the Chukchi and Beaufort seas, July–November 2007. LGL Alaska Report P971-2. Report from LGL Alaska Research Associates, Inc., Anchorage, Ak, LGL Ltd., environmental research associates, King City, Ont., JASCO Research, Victoria, B.C., and Greeneridge Sciences, Inc., Goleta, CA, for Shell Offshore, Inc., ConocoPhillips Alaska, Inc., the National Marine Fisheries Service, silver Springs, MD, and U.S. Fish and Wildlife Service, Anchorage, AK. 445 p. plus appendices.

MacGillivray, A.O., D.E. Hannay, R.G. Racca, C.J. Perham, S.A. Maclean, and M.T. Williams. 2002. Assessment of industrial sounds and vibrations received in artificial polar bear dens, Flaxman Island, Alaska. ExxonMobil Production Co. Draft Report by LGL Alaska Research Associates Inc., Anchorage, AK, and JASCO Research Ltd., Victoria, BC 60 pp.

MacIntyre, K.Q. and K.M. Stafford. 2011. Year-round passive acoustic monitoring of bearded seal vocalizations at three locations in the Beaufort Sea. Poster Presentation: Alaska Marine Science Symposium. Anchorage Alaska. January 2011.

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.

Maher, W.J. 1960. Recent records of the California gray whale (*Eschrichtius glaucus*) along the north coast of Alaska. **Arctic** 13(4):257-265.

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

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

Mate, B.R., G.K. Krutzikowski, and M.H. Winsor. 2000. Satellite-monitored movements of radio-tagged bowhead whales in the Beaufort and Chukchi seas during the late-summer feeding season and fall migration. **Can. J. Zool.** 78:1168-1181.

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 University, Perth, WA, for Australian Petroleum Production Association, Sydney, NSW.

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. 2000b. Marine seismic surveys – a study of environmental implications. **APPEA J.** 40:692-706.

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. and R.A. Davis (eds.) 2002. Marine mammal and acoustical monitoring of Anderson Exploration Ltd.'s open-water seismic program in the southeastern Beaufort Sea. Final report by LGL Ltd., King City, ON., and JASCO Research Ltd., Victoria, B.C. for Devon Canada Corporation, Calgary, AB. 199 p.

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., R.E. Elliot, T.A. Thomas, V.D. Moulton, and W.R. Koski. 2002. Distribution and numbers of bowhead whales in the eastern Alaskan Beaufort Sea during late summer and autumn, 1979-2000. Chapter 9

In 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.

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. 2010. Marine mammal aerial surveys in the arctic 1979-2007. Available online at:

http://www.afsc.noaa.gov/nmml/software/bwasp-comida.php.

MMS. 2009. Bowhead whale feeding ecology study (BOWFEST) in the eastern Beaufort Sea. 2009 Annual report provided to Environmental Studies Program, Alaska Outer Continental Shelf Region, Minerals Management Service, Anchorage, Alaska, submitted through National Marine Mammal Laboratory, Alaska Fisheries Science Center, Seattle Washington. 63pp.

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. and S.D. Treacy. 2005. Aerial surveys of endangered whales in the Beaufort Sea, fall 2002-2004. OCS Study MMS 2005-037. Minerals Manage. Serv., Anchorage, AK. xii + 153 p.

Mooney, T.A., P.E. Nachtigall and S. Vlachos. 2009. Sonar-induced temporary hearing loss in dolphins. **Biol. Lett.** 4(4):565-567.

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. 1992. Summer records of bowhead whales in the northeastern Chukchi Sea. Arctic 45(4):398-400.

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., 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.C. George, K.O. Coyle, and T.J. Weingartner. 1995. Bowhead whales along the Chukotka coast in autumn. **Arctic** 48(2):155-160.

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. Waite, N.A. Friday, and T. Honkalehto. 2002. Distribution and comparative estimates of cetqacean abundance on the central and southeastern Bering Sea shelf with observations on bathymetric and prey associations. Progr. Oceanogr. 55:249-262.

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.

Moore, S.E., K.M. Stafford, D.K. Mellinger, and J.A. Hildebrand. 2006. Listening for large whales in the offshore waters of Alaska. **BioScience.** 56(1):49-55.

Moore, S.E., K.M. Stafford and L.M. Munger. 2010. Acoustic and visual surveys for bowhead whales in the western Beaufort and far northeastern Chukchi Seas. **Deep-Sea Res. II** 57(1-2):153-157.

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 G.W. Miller. 2005. Marine mammal monitoring of a seismic survey on the Scotian Slope, 2003. p. 29-40 in K. Lee, H. Bain and G.V. Hurley, eds. 2005. Acoustic Monitoring and Marine Mammal Surveys in the Gully and Outer Scotian Shelf before and during Active Seismic Programs. **Environmental Studies Research Funds Report** No. 151. 154 p.

Moulton, V.D., W.J. Richardson, T.L. McDonald, R.E. Elliot, and M.T. Williams. 2002. Factors influencing local abundance and haoulut behaviour of ringed seals (Phoca hispida) on landfast ice of the Alaskan Beaufort Sea. **Can. J. Zool**. 80:1900-1917.

Nachtigall, P.E., J.L. Pawloski, and W.W.L. Au. 2003. Temporary threshold shifts and recovery following noise exposure in the Atlantic bottlenose 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.

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. 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.

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

NMFS. 2008. Endangered and threatened wildlife; notice of 12-month finding on a petition to list the ribbon seal as a Threatened or Endangered species. **Fed. Regist.** 73(250, 30 Dec.):79822-79828.

NMFS. 2008b. Final Environmental Impact Statement for issuing annual quotas to the Alaska Eskimo Whaling Commission for a subsistence hunt on bowhead whles for the years 2008 through 2012. Prepared by U.S. Deprtment of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service.

NMFS. 2009. Small takes of marine mammals incidental to specified activities; open-water marine survey program in the Chukchi Sea, Alaska, During 2009-2010; Notice of issuance of an incidental harassment authorization. **Fed. Regist.** 74(206, 27 Oct.):55368-55412.

NMFS. 2010a. Endangered and threatened species; proposed threatened and not warranted status for subspecies and distinct population segments of the bearded seal. **Fed. Regist.** 75(237, 10 Dec.):77496-77515.

NMFS. 2010b. Endangered and threatened species; proposed threatened status for subspecies of the ringed seal. **Fed. Regist.** 75(237, 10 Dec.):77476-77495

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.

NSF. 2004. Guidelines for improved cooperation between arctic researchers and northern communities. Draft cooperation plan from the National Science Foundation, Office of Polar Programs, Arctic Sciences Section and Barrow Arctic Science Consortium (BASC), 23 August 2004. 20p.

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.

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

Popov, L. A. 1976. Status of main ice forms of seals inhabiting waters of the U.S.S.R. and adjacent to the country marine areas. FAO ACMRR/MM/SC/51. 17 pp.

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.

Quakenbush, L., J.J. Citta, J.C. George, R. Small, M.P. Heide-Jorgensen. 2010. Fall and winter movements of bowhead whales (Balaena mysticetus) in the Chukchi Sea and within a potential petroleum development area. **Arctic**. 63(3):289-307.

Quakenbush, L.T. 2009. Summary of maps of fall movements of bowhead whales in the Chukchi Sea. Alaska Dept. of Fish and Game, online at http://wildlife.alaska.gov/management/mm/bow_move_Chukchi_sea.pdf.

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.

Reiser, C.R., B. Haley, D. Savarese, and D. Ireland. 2008. Chapter 3 *In* Funk, D.W., R. Rodrigues, D.S. Ireland, and W.R. Koski (eds.). Joint monitoring program in the Chukchi and Beaufort seas, July–November 2007. LGL Alaska Report P971-2. Report from LGL Alaska Research Associates, Inc., Anchorage, Ak, LGL Ltd., environmental research associates, King City, Ont., JASCO Research, Victoria, B.C., and Greeneridge Sciences, Inc., Goleta, CA, for Shell Offshore, Inc., ConocoPhillips Alaska, Inc., and National Marine Fisheries Service, and U.S. Fish and Wildlife Service.

Reiser, C.M., B. Haley, J.A. Beland, D.M. Savarese, D.S. Ireland, and D.W. Funk. 2009. Evidence for short−range movements by phocid species in reaction to marine seismic surveys in the Alaskan Chukchi and Beaufort seas. 18th Conference on the biology of marine mammals, Quebec City, Québec, Canada.

Reiser, C. M, D. W. Funk, R. Rodrigues, and D. Hannay. (eds.) 2010. Marine mammal monitoring and mitigation during open water seismic exploration by Shell Offshore, Inc. in the Alaskan Chukchi Sea, July–October 2009: 90-day report. LGL Rep. P1112-1. Rep. from LGL Alaska Research Associates Inc. and JASCO Research Ltd. for Shell Offshore Inc, Nat. Mar. Fish. Serv., and U.S. Fish and Wild. Serv. 104 pp, plus appendices.

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., 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. (ed.) 1999. Marine mammal and acoustical monitoring of Western Geophysical's open-water seismic program in the Alaskan Beaufort Sea, 1998. LGL Rep. TA2230-3. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for Western Geophysical, Houston, TX, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 390 p.

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., 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. 1995a. Marine Mammals and Noise. Academic Press, San Diego. 576 p.

Richardson, W.J., C.R. Greene Jr., J.S. Hanna, W.R. Koski, G.W. Miller, N.J. Patenaude and M.A. Smultea. 1995b. Acoustic effects of oil production activities on bowhead and white whales visible during spring migration near Pt. Barrow, Alaska—1991 and 1994 phases: sound propagation and whale responses to playbacks of icebreaker noise. OCS Study MMS 95-0051; LGL Rep. TA954. Rep from LGL Ltd, King City, Ont. And Greeneridge Sciences Inc., Santa Barbara, CA, for U.S. Minerals Manage. Serv., Anchorage AK, and Herndon VA. 539 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.

Roth, E. H, and V. Schmidt. 2010. Noise levels generated by research icebreakers and marine seismic sources in the deep-water, Arctic Ocean. MPL Tech. Mem. 527.

Rugh, D. (ed.) 2009. Bowhead Whale Feeding Ecology Study (BOWFEST) in the Western Beaufort Sea; 2008 Annual Report. MMS-4500000120. Produced through the National Marine Mammal Laboratory, Alaska Fisheries Science Center, NMFS, NOAA, 7600 Sand Point Way, NE Seattle, WA 98115-6349.

Rugh, D.J., and M.A. Fraker. 1981. Gray whale (Eschrichtius robustus) sightings in eastern Beaufort Sea. **Arctic** 34(2):186-187.

Rugh, D.J., R.C. Hobbs, J.A. Lerczak, and J.M. Breiwick. 2003. Estimates of abundance of the Eastern North Pacific stock of gray whales 1997 to 2002. Paper SC/55/BRG13 presented to the IWC Scientific Committee, May 2003. 18pp.

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., D. DeMaster, A. Rooney, J. Breiwick, K. Sheldon and S. Moore. 2003. A review of bowhead whale (*Balaena mysticetus*) stock identity. **J. Cetacean Res. Manage.** 5(3):267-279.

Rugh, D.J., R.C. Hobbs, J.A. Lerczak and J.M. Breiwick. 2005. Estimates of abundance of the eastern North Pacific stock of gray whales (*Eschrichtius robustus*) 1997-2002**. J. Cetac. Res. Manage.** 7(1):1-12.

Rugh, D., J. Breiwick, M. Muto, R. Hobbs, K. Shelden, C. D'Vincent, I.M. Laursen, S. Reif, S. Maher, and S. Nilson. 2008. Report of the 2006-2007 census of the eastern North Pacific stockof gray whales. Report prepared by the National Marine Mammal Laboratory, Alaska Fissheries Science Center, NMFS, NOAA, and Intersea Foundation Inc.

Savarese, D.M., C.R. Reiser, D.S. Ireland, and R. Rodrigues. 2010. Beaufort Sea vessel-based monitoring program. (Chapter 6) In: Funk, D.W, D.S. Ireland, R. Rodrigues, and W.R. Koski (eds.). 2010. Joint Monitoring Program in the Chukchi and Beaufort seas, open water seasons, 2006–2008. LGL Alaska Report P1050-3, Report from LGL Alaska Research Associates, Inc., LGL Ltd., Greeneridge Sciences, Inc., and JASCO Research , Ltd., for Shell Offshore, Inc. and Other Industry Contributors, and National Marine Fisheries Service, U.S. Fish and Wildlife Service. 499 p. plus Appendices.

Santulli, A., C. Messina, L. Ceffa, A. Curatolo, G. Rivas, G. Fabi, and V. Damelio. 1999. Biochemical responses of European sea bass (*Dicentrachus labrax*) to the stress induced by offshore experimental seismic prospecting. **Mar. Poll. Bull.** 38(12):1105-1114.

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.

Scholik-Schlomer, A.R. in press. Status of NOAA's guidelines for assessing impacts of anthropogenic sound on marine mammals. *In*: A.N. Popper and A.D. Hawkins (eds.), Effects of noise on aquatic life. Springer.

Sekiguchi, K., T. Uyama, and K. Yamshiro. 2008. Cetacean sighting survey during T/S Oshoro Maru Bering and Chukchi Sea cruise, 1 July–28 August 2007.

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, 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., and M.O. Hammill. 1981. Ecology of the ringed seal, *Phoca hispida*, in its fast ice breeding habitat. Canadian Journal of Zoology 59: 966–981.

Smith, T.G., M.O. Hammill, and G. Taugbøl. 1991. A review of the developmental, behavioural and physiological adaptations of the ringed seal, *Phoca hispida*, to life in the arctic winter. **Arctic** 44(2):124-131.

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. and M. Holst. 2003. Marine mammal monitoring during Lamont-Doherty Earth Observatory's seismic study in the Hess Deep area of the Eastern Equatorial Tropical Pacific, July 2003. LGL Rep.

TA2822-16. Rep. from LGL Ltd., King City, ON, for Lamont-Doherty Earth Observatory, Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 68 p.

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.

Southall, B.L., A.E. Bowles, W.T. Ellison, J.J. Finneran, R.L. Gentry, C.R. Greene Jr., D. Kastak, D.R. Ketten, J.H. Miller, P.E. Nachtigall, W.J. Richardson, J.A. Thomas, and P.L. Tyack. 2007. Marine mammal noise exposure criteria: initial scientific recommendations. **Aqua. Mam.** 33(4), 411-521.

Stafford, K.M., S.E. Moore, M. Spillane, S. Wiggins. 2007. Gray whale calls recorded near Barrow, Alaska, throughout the winter of 2003-04. **Arctic** 60(2): 167-172.

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., 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.

Stringer, W., S. Barrett, and L. Schreurs. 1980. Nearshore ice conditions and hazards in the Beaufort, Chukchi, and Bering Seas. Report UAGR #274. Available from the Geophysical Institute, University of Alaska Fairbanks, 903 Koyokuk Drive, Fairbanks, Alaska 99775-7320, U.S.A.

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., 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.

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., L.F. Lowry, and K.J. Frost. 2005. Distribution and movements of beluga whales from the eastern Chukchi Sea stock during summer and early autumn. OCS Study MMS 2005-035. 35 p.

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., W.R. Koski, and D.S. Ireland. 2009. Chukchi Sea nearshore aerial surveys. (Chapter 4) In: Funk, D.W., D.S. Ireland, R. Rodrigues, and W.R. Koski (eds.). 2010. Joint Monitoring Program in the Chukchi and Beaufort seas, open water seasons, 2006–2008. LGL Alaska Report P1050-3, Report from LGL Alaska Research Associates, Inc., LGL Ltd., Greeneridge Sciences, Inc., and JASCO Research , Ltd., for Shell Offshore, Inc. and Other Industry Contributors, and National Marine Fisheries Service, U.S. Fish and Wildlife Service. 499 p. plus Appendices.

Thomas, T., W.R. Koski and D.S. Ireland. 2010. Chukchi Sea nearshore aerial surveys. (Chapter 4) In: Funk, D.W, D.S. Ireland, R. Rodrigues, and W.R. Koski (eds.). 2010. Joint Monitoring Program in the Chukchi and Beaufort seas, open water seasons, 2006–2008. LGL Alaska Report P1050-3, Report from LGL Alaska Research Associates, Inc., LGL Ltd., Greeneridge Sciences, Inc., and JASCO Research , Ltd., for Shell

Offshore, Inc. and Other Industry Contributors, and National Marine Fisheries Service, U.S. Fish and Wildlife Service. 499 p. plus Appendices.

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.

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.

Treacy, S.D., J.S. Gleason and C.J. Cowles. 2006. Offshore distances of bowhead whales (*Balaena mysticetus*) observed during fall in the Beaufort Sea, 1982-2000: an alternative interpretation. **Arctic** 59(1):83-90.

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.

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

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). 1996. Beaufort Sea Planning Area Oil and Gas Lease Sale 144 Final Environmental Impact Statement.

Wardle, C.S., T.J. Carter, G.G. Urquhart, A.D.F. Johnstone, A.M. Ziolkowski, G. Hampson and D. Mackie. 2001. Effects of seismic air guns on marine fish. **Cont. Shelf Res.** 21(8-10):1005-1027.

White, M.J., Jr., J. Norris, D. Ljungblad, K. Baron and G. di Sciara. 1978. Auditory thresholds of two beluga whales (*Delphinapterus leucas*). HSWRI Tech. Rep. 78-109. Rep. from Hubbs/Sea World Res. Inst., San Diego, CA, for Naval Ocean Systems Center, San Diego, CA. 35 p.

Williams, M.T. and J.A. Coltrane (eds.). 2002. Marine mammal and acoustical monitoring of the Alaska Gas Producers Pipeline Team's open water pipeline route survey and shallow hazards program in the Alaskan Beaufort Sea, 2001. LGL Rep. P643. Rep. from LGL Alaska Res. Assoc. Inc., Anchorage, AK, for BP Explor. (Alaska) Inc., ExxonMobil Production, Phillips Alaska Inc., and Nat. Mar. Fish. Serv. 103 p.

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.

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

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

Wynne, K. 1997. Guide to Marine Mammals of Alaska. Alaska Sea Grant College Program, University of Alaska, Fairbanks.

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

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

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.

Zerbini, A.N., J.M. Waite, J.L. Laake, and P.R. Wade. 2006. Abundance, trends and distribution of baleen whales off western Alaska and the central Aleutian Islands. Deep-sea Research, Part 1. 53(11):1772-1790.

Zykov, M., T. Deveau, and D. Hannay, 2010. Modeling of Underwater Sound from GXT's Beaufort 4 Source in the Alaskan Beaufort Sea, Version 2.2. Report by JASCO Applied Sciences Ltd. for LGL, Alaska.

APPENDIX A:
DESCRIPTION OF VESSELS PROPOSED FOR THE 2012 GEOPHYSICAL PROJECT

Vessel Specifications

Geo Arctic

The M/V *Geo Arctic* (Fig. A1) is a Russian-flagged seismographic research ship built in 1988. ION plans to use this vessel to conduct a 2D seismic survey in the Alaskan Beaufort Sea in 2012. The *Geo Arctic* is 81.8 m long, with a beam of 14.8 m, a draft of 5.4 m, and a gross tonnage of 2833 tons. It can travel at a speed of 12 kts, and it has a fuel capacity of 710 t. The main engine is a Zgoda-Sulzer 6ZL 40/48 engine. Details of the ships characteristics are presented below.

Figure A1. The seismic source vessel M/V *Geo Arctic*.

GeoArctic Ship Characteristics

VESSEL TECHNICAL INFORMATION

MAIN DATA	
SHIP NAME	Geo Arctic
CALL SIGN	UGXK
OWNER	Sevmorneftegeofizika (SMNG)
PREVIOUS NAME	Akademik Nametkin
FLAG	Russia
PORT OF REGISTRY	Murmansk
MMSI No./ IMO No.	273458600/8409018
SEISMIC TYPE	Seismic vessel 2D Research
DATE OF BUILT/REBUILT	1988/1997 Norway
YARD BUILT	Varskego Shipyard, Szczecyn (Poland)
YARD NO.	109304
CLASSIFICATION	KM UL (1) A2 (Russian) Ice class

PRINCIPAL PARTICULARS

GRT. INTERNATIONAL	2833
NRT. INTERNATIONAL	850
LIGHTSHIP DICPLACEMENT	3631
DEADWEIGHT	1319
LOA (MTRS)	81.86
LBP (MTRS)	73.6
BREADTH (MOULDED)	14.81
BREADTH (EXTREME)	14.81
DEPTH (MOULDED)	7.5
DEPTH (EXTREME)	7.5
DRAFT (LIGHTEST)	4.8
DRAFT (MAX)	5.4
DRAFT (MEAN)	5.23
Height waterline to highest fixed antenna	30

CAPACITIES AND ENDURANCES

PORTABLE F.W. CAPACITY	200 t
FW PROD./DAY	8 t
F.W. SOURCE	Evaporator
FUEL CAPACITY (MAX)	710 t
FUEL CAPACITY (USEFUL)	680 t
FUEL TYPE	Marine Gas Oil (Sulphur contents – less than 0.5%)
L.O. CAPACITY	17 t
STREAMER OIL CAPACITY	10 t
S.W. BALLAST CAPACITY	420 t
TRANSIT SPEED MAX	13 knots

TRANSIT SPEED ECON	11 knots
24HR F/C AT MAX TRAN. SPEED	12,5 t
24HR F/C AT ECON TRAN. SPEED	10 t
MAX. DAYS AT MAX TRAN. SPEED	57 days
MAX. DAYS AT ECON TRAN. SPEED	71 days
PRODUCTION SPEED MAX	5.5 knots
PRODUCTION SPEED MIN	3.5 knots
PRODUCTION SPEED (MEAN)	4.5 knots
24HR F/C AT MAX PROD. SPEED	10,5 t
24HR F/C AT ECON PROD. SPEED	8 t
MAX. DAYS AT MAX PROD. SPEED	67 days
24HR FUEL CONS. IN PORT	2 t

BRIDGE EQUIPMENT

NO. 1 RADAR	1xKelvin Hughes,6000,Nucleus 2, APRA (10 cm), Japan
NO. 2 RADAR	1xFURUNO (FR-2015), APRA (3 cm), Japan
GYRO COMPASS	1xPlatch,Navigat II with LehmkuhlLR 40 1x Sg Brown 1000G
AUTO PILOT	Simrad AP 9 mk 3
DIFFERENTIAL GPS	STARFIX MN8 DGPS & STARFIX SPOT DGPS
GPS RECEIVER	FURUNO, GP-50 MK II, , Japan
SPEED LOG	1x Atlas Dolog
ECHO SOUNDER	GEL-3, Russia
NO. 1 VHF	SKANTI, VHF-3000 (Denmark)
NO. 2 VHF	Sailor, VHF RT 20470
NAVTEX	FURUNO NX-500
WIND SENSOR	Aanderaa 3017 Speed

COMMUNICATION EQUIPMENT

GMDSS	A1,A2 and A3
SATELITE FIXED LINE	TELENOR SEALINK LIGHT, NORSAT
INMARSAT TYPE B	SATURN B, PHONE HIGN SPEED DATA MODEM;
INMARSAT TYPE FLEET	NERA F77, Norway
INMARSAT TYPE C	SKANTI SCANSAT-C,427300578
No; TLX 427300236	Denmark
INMARSAT “B” No. (Voice)	
INMARSAT “B” No. (Fax)	
INMARSAT “FLEAT” No. (Voice)	
INMARSAT “FLEAT” No. (Fax)	
E-mail	
TELEX	FURUNO PP-510 No.:0102495
TELEFAX No 2 Inmarsat B	Panafax UF-V60

MAIN TRANSMITTER	Scanti TRP-7201
RESERVE TRANS.	
MAIN RECEIVER	
RESERVE RECVR	
WATCHKEEPING RECEIVER	Sailor GMDSS A3
WEATHER FAX	INEY-P (Russia)
PORTABLE VHF Max 6W Band: 150-163 Mhz	3 pcs Tron GMDSS max 4 W band
PORTABLE VHF Band: 156-163 Mhz	3 pcs Tron GMDSS max 4 W band
TRANSMITTER SSB / AM / Max 1,5KW	
TRANSMITTER SSB / AM / Max 400W	
Non-directional beacon	AS Tele Supply TS-20B
INMARSAT “C” Message terminal	SKANTI PC-9000,
PRINTER	OKI, Microline 280,
VHF DSC	SKANTI DSC-3000
VHF	SKANTI VHF-3000
HF SSB	SKANTI TU-7201 Max. 400W
Wathkeeper	Sailor GMDSS A3
HF SSB DSC Watchreceiver	SKANTI DSC-3000
HF SSB TELEX / DSC	
Radiotelex Message Terminal	
GMDSS Alarm unit	SKANTI AP-9000
CONTROL UNIT	SKANTI CU-7201 No.:43627
VHF Portable	3xNAVICO SRH-50 GMDSS

MACHINERIES

PROPELLER	4 blades: VPP: LH 13 NM
SPARE PROP	2 blades: VPP: LH 13 NM
PROPULSION TYPE	Diesel engines, VPP, Gear
PROPULSION MOTORS	
MAIN ENGINES	6ZL 40/48 Zgoda-Sulzer, 3090 kW (Poland)
AUX. ENGINES	2 pcs, 8AL 20/24 Cigielski, 548 kW
AUX. ALTERNATORS	2 GD8SW0630-50/02, each 548 kW
SHAFT ALTERNATOR	GNB-136c/03, 1200 Kw
BOW THRUSTERS	FU-45-LTC-1225, 442kW, Brunvoll A/S, NORWAY
EMERG. GENERATOR	217 Ma-39H6 121 kW, Warsaw (Poland)
F.W. MAKER	Aqua Set 802
EVAPORATOR	Aqumar 16 t/d
BOILERS	VX 740A-15 Stochna Gdanska (Poland)
OILY WATER SEPARATOR	OB-5M
U.P.S. EQUIP. FOR INSTR. ROOM	PS 30/P5.0/NO2; PS 30/5.0/XTS/F FISKARS
STEERING GEAR	HYDROSTER MS 200-11-2/SI (Poland)
INCINERATOR	SO1 WARMA (Poland)

HULL OUTFITTINGS

SHIP/AIR COMM.	3 x NAVICO SRH-50 GMDSS No.:10548,10549,10556
ANCHORS	2 Holla
WINDLASS	G5A0101
CAPSTAN	WKS-2 Szczecyn, Poland
ACCOMMODATION-TTL No.of CABINS	35
TTL NO. SINGLE BED CABINS	13
TTL NO. DOUBLE BED CABINS	22
CRANES Main	R 4/12.5, 3t

VESSEL SAFETY EQUIPMENT

Safety MANNING LEVEL	55 person
LIFERAFTS TYPE	20 DK
MAN OVERBOAT LIFERAFTS	2 x 6 man life-rafts (2 x Jonbuoy as backup)
MAN OVERBOARD BOAT	LR-6
MOB ENGINE	Yanmar 27D, 272 kW
WORK BOAT	Norpower 22, 6 persons
WORK BOAT ENGINE	CUMMINS 6VNF 5,9-M2, 272 kW
FRC	7.5 Magnum, ”Norpower”, Norway
SURVIVAL SUITS	44 x V-20 / 11 x /Helli Hansen
WORK WEST	4 x Crewsaver
LIFE JACKETS	55 x Aquavel MK II/ 51 x Pasratunkowy Stogi II
EPIRB (No/Type)	TRON-40S , Norway
EMERGENCY RADIOS	SailorGMDSS A3
EMERGENCY BEACONS	1 x McMurdo E3 EPIB
RADAR TRANSPONDERS	2 x Jotron TronSart
FIXED FIRE FIGHTING SYS IN E/R	CO_2
FIXED FFE IN COMPR. ROOM	CO_2
FIXED FFE IN CABLE STORE	AFFF
FIXED FFE FOR STREAMER REELS	AFFF
MAIN FIRE PUMP	2 pcs – 40 m^3/h – 100 m^3/h
MAIN FIRE PUMP (locn.)	Main Engine Room
EMERG. FIRE PUMP (locn.)	Auxiliary Engine Room

ENERGY SOURCE

SOUCE TYPE	G-Air Guns
SUB-ARRAYS NO	4

GUNS NO PER SUB-ARRAY	10
COMPRESSORS TYPE	2X LMF,Type 31/138D, Piston VCS 2218 W14, Screw Sigma S-G; 4x EK-30
COMPRESSORS CAPACITY	2 x 1100 CFM (cubic feet per minute); 4 x 400CFM
NOMINAL SOURCE PRESSURE	2000 p.s.i.
SOURCE VOLUME	4820 cub.in.
MAXIMUM PEAK TO PEAK	144 barm at 8m depth (Filter: 3,0/18-206,0/72 SEAL)
MAXIMUM PEAK TO BUBBLE	10,2 barm at 8m depth (Filter: 3,0/18-206,0/72 SEAL)
SUBARRAY SEPARATION	10 m - 20 m – 10m
MAX. SOURCE WIDTH	40 m
SUBARRAY LENGTH	12 m
DEPTH RANGE	3 – 10 m
SOURCE CONTROLLER	Digishot
RECORDING SYSTEM	
TYPE	Sercel 408XL (SEAL) 5.2
CHANNELS NO	960 channels
AUXILIARIES CHANNELS	60
TAPE RECORDING ABILITY	3490E, 3590 ,3590E, DLT, LTO IBM 3580
RECORDING FORMAT	4byte, SEG-D revision 2, demultiplexed, 32 bit IEEE, code 8058
PLOTTER SYSTEM	OYO-GS 624-2 Plotter
PRIMARY STORAGE MEDIA	SeisNet RAID system 3800 Gb
SECONDARY STORAGE MEDIA	IBM 3590 Tape recorder

STREAMER SYSTEM

TYPE	Sercel SEAL 24 bit digital
CAPACITY	12000 m
SECTION LENGTH	150 m
DIAMETER SECTION	50 mm
HYDROPHONE	NH 95-200
HYDROPHONE PER GROUP	16 / 12,5 m
GROUP SENSITIVITY	17.4 V / Bar
GROUP CAPACITANCE	256 nF / 12,5m
NO OF DATA CHANNELS / MODULE	2
NO OF DIGITIZER BITS	24-bits
CABLE OIL	Isopar M
TAIL BUOYS	Partnerplast, SeaTrack 220
NO OF STREAMER WINCH	2
NO OF LEAD-IN WINCH	2

STREAMER CONTROL DEVICE

MANUFACTURER	ION Inc, USA
TYPE	DigiCource - 5011E
LEVELER AND COMPASS	DigiCource - 5011E
STREAMER COMMUNICATION	Serial FSK (Digital)
ACCURACY COMPASS	+/- 0.5 deg
DEPTH ACCURACY	+/- 0.15 m
LENGTH RANGE	122 m

NAVIGATION

INTEGRATED NAVIGATION SYSTEM	SPECTRA 12.10.1
PRIMARY NAVIGATION	MRDGPS Starfix v.7.2, Fugro, INMARSAT B, NERA F77
SECONDARY NAVIGATION	MultiFix 5, v.1.02, Fugro, INMARSAT B, NERA F77
TAILBUOY POSITIONING	RGPS SeaTrack 220, Fugro
GYRO COMPASS	SG Brown Meridian
ECHO SOUNDER	SIMRAD EA600

Polar Prince

The M/V *Polar Prince* (Fig. A2) is a Medium Class 100A ice-breaking ship that will be used as the escort icebreaker during the proposed project. The *Polar Prince* is a former Canadian Coast Guard vessel. In 1986, the ship was totally rebuilt by the Canadian Coast Guard to meet all modern specifications at a cost of $25 million. Asbestos was removed, electronics replaced, engines replaced and the bow section was replaced forward of the superstructure. It has a double hull and a full bubbler system for icebreaking.

The *Polar Prince* is 67.1 m long, with a beam of 15 m and a draft of 6 m. It can travel at a speed of 14.5 kts, but cruising speed is 11 kts. It has a fuel capacity of 701.5 m^3, and a net tonnage of 613 tonnes. It uses diesel electric propulsion, 4 x Morse-Fairbanks 38 D 8 1/8 diesel engine, 3 x 3408 CAT generators, and two fixed blade Superston 70 propellers.

Figure A2. The icebreaker M/V *Polar Prince*.

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Polar Prince *Ship Characteristics*

Name	M/V Polar Prince
Vessel Type	Ice Breaker - Cargo
Function	Site Survey Platform
Flag	Canada
Port of Registry	Ottawa
Owner	GX Technology Canada Ltd.
Year/Site of Construction	1959 / Davie Shipbuilding, Lauzon Quebec
Refit	1979, 1987, 2010
Certification	Transport Canada Marine Safety & DNV 1A1
Ice Classification	Lloyds 100A (Arctic Class 1+)
Official Number	310141
Vessel IMO ID	5329566

Call Sign	CFK 9552
Length	220.0 ft (67.06 m)
Beam	49.2 ft (15.00 m)
Draft	19.7 ft (6.00 m)
Gross Tonnage	2152 tonnes
Net Tonnage	613 tonnes
Cruising Speed	11.0 knots
Maximum Speed	14.5 knots
Cruising Range	10,000 Nautical Miles @ 11 Knots
Fuel Consumption	6 Tonnes/day @ 10 knots
Endurance	As above
Fuel Capacity	701.46 cubic meters
Lube Oil Capacity	12.93 cubic meters
Jet Fuel Capacity	5.15 cubic meters
Ballast Water Capacity	496.62 cubic meters
Fresh Water Capacity	359.24 cubic meters
Freshwater-Maker Capacity	25 cubic meters per day
Cargo Capacity	900.84 cubic meters
Accommodation Capacity	60
Life Rafts	6 x Zodiac-DBC 25 Man SOLAS approved.
MOB Boat	1 x Zodiac RIBO 600 FRC with SOLAS Davit
Main engines	4 x Morse-Fairbanks 38 D 8 1/8 Diesels.
Propulsion	Diesel-Electric (DC) Twin
Propellers	2 x Fixed blade Superston 70
Total Horsepower	5123 hp (3820 kW)
Gear	n/a
Service Generators	3 x Caterpillar 3408
Emergency Generator	1 x Deutz A6 M816
Clean Power / UPS	N/A
Auxiliary Machinery	Caterpillar 3512 DI Bubbler
Crane #1	Alaska Marine MK-1837 10 MT
Crane #2	Hiab Sea Crane 5 MT
Crane #3	Hiab Sea Crane 5 MT
Navigation:	
Gyro Compass	2 x Sperry MK37
Auto Pilot	ComNav Admiral
Radar	Radar #1 Furuno X-Band ARPA FAR2127 Radar #2 Furuno S-Band FAR2137S MAXSEA 21X7 Computer Plotting System
GPS	Furuno GP-3204
Ships Fathometer	ELAC LAZ 72
Communications:	
VHF Crew Radios	ICOM M72 and Motorola HT-750LS
VHF Marine Radios	Furuno 8800S GMDSS

MF/HF Radio	2 x Furuno FS2570
Inmarsat C	Thrane & Thrane Sat C
Number	431697644
V-Sat	
Iridium	Globe Wireless OpenPort
Number (Bridge)	881677712535
Number (GXT Office)	881677712536
Firefighting Equipment:	
Extinguishing Systems	Engine Room - Halon 1301 Incinerator, Cargo Hold #2, Paint Store – CO_2
Fire Pump	3 of.
Alarm System	Fire Alarm Secutron MR-2200 System
Pollution Equipment:	
Sewage System	FAST D3 (55 Person Continuous) TC and USCG Approved
Bilge	Sigma Max, 3.5 cubic meter per hour
Incinerator (Containerized)	Atlas 600SL B WS P MARPOL and Class approved for solid waste and sludge.
Helipad (deck will be dismantled for this program)	Yes, Bell 206 or equivalent

APPENDIX B: AIRGUN DESCRIPTION AND SAFETY RADII

Airgun Description

The seismic source for the proposed geophysical survey will be comprised of 26 active airguns with a total operating volume of 4450 in^3 (two airguns in the 28-airgun array will be inactive and serve only as spares). The 28 airguns will be distributed in two sub-arrays comprised of 14 airguns each (Fig. B-1). Individual airgun sizes range from 70 to 380 in^3. Airguns will be operated at 2000 psi. The sub-arrays will be towed 25 m (82 ft) behind the source vessel, though this may need to be adjusted (e.g., up to 50 m; 164 ft) if conditions warrant, and at a water depth of ~8.5 m. The seismic vessel will travel along pre-determined lines at speeds ranging from ~4 to 5 knots. The airgun array will discharge every 37.5 m or about every 18 seconds.

The nominal zero-to-peak source pressure level @ 1 m for each pulse is estimated as 250 dB re 1µPa (for 1-2000 Hz). The source pressure averaged over the length of the pulse (rms) is estimated to be 232 dB re 1µPa @ 1 m and the sound exposure level (SEL) at 1 m from the source is estimated as 229 dB re 1 µPa^2 s. The pulse length (90% energy) is estimated to be 0.5 s near the source (Zykov et al. 2010).

The seismic source vessel will also tow a streamer which will receive the reflected signals from the seabed and transfer the data to an on-board processing system. ION is proposing to use a streamer called the DigiSTREAMER. The streamer will be 4.5–9 km long, and will be towed ~9.5 m below the water surface. Approximately every 300 m along the streamer, DigiFIN units are attached to maintain the desired deployment depth. The DigiFIN units (manufactured by ION Geophysical) also provide lateral control for avoiding deep ice keels, acoustic positioning, and depth measurements. The survey vessel will have limited maneuverability while towing the streamer and thus will require a 10 km run-in for the start of a seismic line, and a 4-5 km run-out at the end of the line.

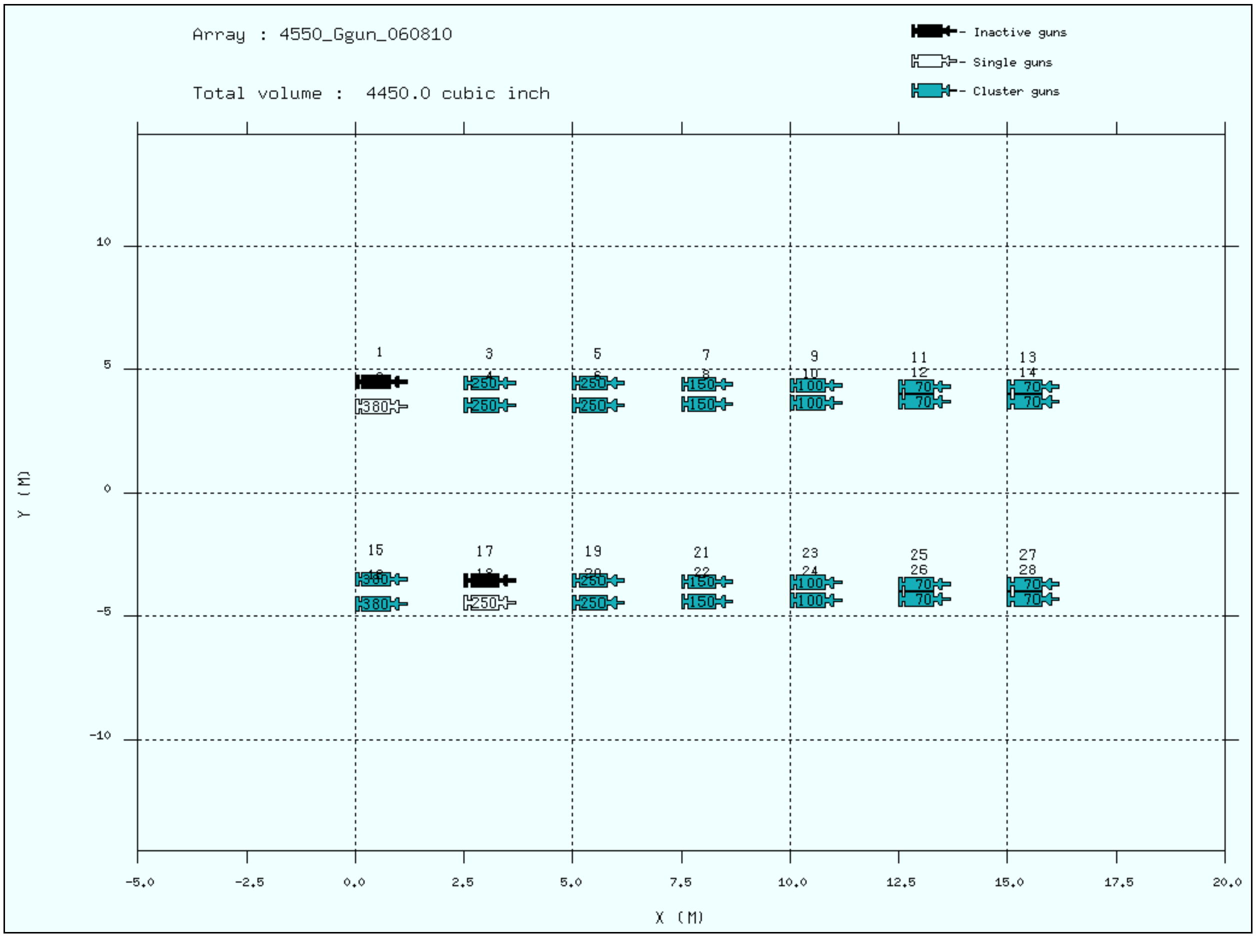

FIGURE B-1. Geometry layout of 4450 in^3 array. Tow direction is to the right; tow depth is 8.5 m.

Literature Cited

Zykov, M., T. Deveau, and D. Hannay, 2010. Modeling of Underwater Sound from GXT's Beaufort 4 Source in the Alaskan Beaufort Sea, Version 2.2. Report by JASCO Applied Sciences Ltd. for LGL, Alaska.

APPENDIX C:

REVIEW OF THE EFFECTS OF AIRGUN SOUNDS ON MARINE MAMMALS[3]

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

1. Categories of Noise Effects

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

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

2. Hearing Abilities of Marine Mammals

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

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

2. Critical ratio (the signal-to-noise ratio required to detect a sound at a specific frequency in the presence of background noise around that frequency).

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

3. The ability to determine sound direction at the frequencies under consideration.
4. The ability to discriminate among sounds of different frequencies and intensities.

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

2.1 Toothed Whales (Odontocetes)

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

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

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

Despite the relatively poor sensitivity of small odontocetes at the low frequencies that contribute most of the energy in pulses of sound from airgun arrays, airgun sounds are sufficiently strong, and contain sufficient mid- and high-frequency energy, that their received levels sometimes remain above the hearing thresholds of odontocetes at distances out to several tens of kilometers (Richardson and Würsig 1997). There is no evidence that most small odontocetes react to airgun pulses at such long distances. However, beluga whales do seem quite responsive at intermediate distances (10–20 km) where sound levels are well above the ambient noise level (see below).

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

2.2 Baleen Whales (Mysticetes)

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

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

2.3 Seals and Sea Lions (Pinnipeds)

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

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

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

2.4 Manatees and Dugong (Sirenians)

The West Indian manatee can apparently detect sounds and low-frequency vibrations from 15 Hz to 46 kHz, based on a study involving behavioral testing methods (Gerstein et al. 1999, 2004). A more recent study found that, in one Florida manatee, auditory sensitivity extended up to 90.5 kHz (Bauer et al. 2009). Thus, manatees may hear, or at least detect, sounds in the low-frequency range where most seismic energy is released. It is possible that they are able to feel these low-frequency sounds using vibrotactile receptors or because of resonance in body cavities or bone conduction.

Based on measurements of evoked potentials, manatee hearing is apparently best around 1–1.5 kHz (Bullock et al. 1982). However, behavioral tests suggest that best sensitivities are at 6–20 kHz (Gerstein et al. 1999) or 8–32 kHz (Bauer et al. 2009). The ability to detect high frequencies may be an adaptation to shallow water, where the propagation of low frequency sound is limited (Gerstein et al. 1999, 2004).

2.5 Sea Otter and Polar Bear

No data are available on the hearing abilities of sea otters (Ketten 1998), although the in-air vocalizations of sea otters have most of their energy concentrated at 3–5 kHz (McShane et al. 1995; Thomson and Richardson 1995). Sea otter vocalizations are considered to be most suitable for short-range communication among individuals (McShane et al. 1995). However, Ghoul et al. (2009) noted that the in-air "screams" of sea otters are loud signals (source level of 93–118 dB re 20 μPa_{pk}) that may be used over larger distances; screams have a frequency of maximum energy ranging from 2 to 8 kHz. In-air audiograms for two river otters indicate that this related species has its best hearing sensitivity at the relatively high frequency of 16 kHz, with some sensitivity from about 460 Hz to 33 kHz (Gunn 1988). However, these data apply to a different species of otter, and to in-air rather than underwater hearing.

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

3. Characteristics of Airgun Sounds

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

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

Several important mitigating factors need to be kept in mind. (1) Airgun arrays produce intermittent sounds, involving emission of a strong sound pulse for a small fraction of a second followed by several seconds of near silence. In contrast, some other sources produce sounds with lower peak levels, but their sounds are continuous or discontinuous but continuing for longer durations than seismic pulses. (2) Airgun arrays are designed to transmit strong sounds downward through the seafloor, and the amount of sound transmitted in near-horizontal directions is considerably reduced. Nonetheless, they also emit sounds that travel horizontally toward non-target areas. (3) An airgun array is a distributed source, not a point source. The nominal source level is an estimate of the sound that would be measured from a theoretical point source emitting the same total energy as the airgun array. That figure is useful in calculating the expected received levels in the far field, i.e., at moderate and long distances, but not in the near field. Because the airgun array is not a single point source, there is no one location within the near field (or anywhere else) where the received level is as high as the nominal source level.

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

Seismic sound pulses received at any given point will arrive via a direct path, indirect paths that include reflection from the sea surface and bottom, and often indirect paths including segments through the bottom sediments. Sounds propagating via indirect paths travel longer distances and often arrive later than sounds arriving via a direct path. (However, sound traveling in the bottom may travel faster than that in the water, and thus may, in some situations, arrive slightly earlier than the direct arrival despite traveling a greater distance.) These variations in travel time have the effect of lengthening the duration of the

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

received pulse, or may cause two or more received pulses from a single emitted pulse. Near the source, the predominant part of a seismic pulse is ~10–20 ms in duration. In comparison, the pulse duration as received at long horizontal distances can be much greater. For example, for one airgun array operating in the Beaufort Sea, pulse duration was ~300 ms at a distance of 8 km, 500 ms at 20 km, and 850 ms at 73 km (Greene and Richardson 1988).

The rms level for a given pulse (when measured over the duration of that pulse) depends on the extent to which propagation effects have "stretched" the duration of the pulse by the time it reaches the receiver (e.g., Madsen 2005). As a result, the rms values for various received pulses are not perfectly correlated with the SEL (energy) values for the same pulses. There is increasing evidence that biological effects are more directly related to the received energy (e.g., to SEL) than to the rms values averaged over pulse duration (Southall et al. 2007).

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

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

4. Masking Effects of Airgun Sounds

Masking is the obscuring of sounds of interest by interfering sounds, generally at similar frequencies (Richardson et al. 1995). Introduced underwater sound will, through masking, reduce the effective communication distance of a marine mammal species if the frequency of the source is close to that used as a signal by the marine mammal, and if the anthropogenic sound is present for a significant fraction of the time (Richardson et al. 1995). If little or no overlap occurs between the introduced sound and the frequencies used by the species, communication is not expected to be disrupted. Also, if the introduced sound is present only infrequently, communication is not expected to be disrupted much if at all. The duty cycle of airguns is low; the airgun sounds are pulsed, with relatively quiet periods between pulses. In most situations, strong airgun sound will only be received for a brief period (<1 s), with these sound pulses being separated by at least several seconds of relative silence, and longer in the case of deep-penetration surveys or refraction surveys. A single airgun array might cause appreciable masking in only one situation: When propagation conditions are such that sound from each airgun pulse reverberates strongly and persists for much or all of the interval up to the next airgun pulse (e.g., Simard et al. 2005; Clark and Gagnon 2006). Situations with prolonged strong reverberation are infrequent, in our experience. However, it is common for reverberation to cause some lesser degree of elevation of the background level between airgun pulses (e.g., Guerra et al. 2009), and this weaker reverberation presumably reduces the detection range of calls and other natural sounds to some degree.

Although masking effects of pulsed sounds on marine mammal calls and other natural sounds are expected to be limited, there are few specific studies on this. Some whales continue calling in the presence of seismic pulses and whale calls often can be heard between the seismic pulses (e.g., Richardson et al. 1986; McDonald et al. 1995; Greene et al. 1999a,b; Nieukirk et al. 2004; Smultea et al. 2004; Holst et al. 2005a,b, 2006; Dunn and Hernandez 2009). However, there is one recent summary report indicating that calling fin whales distributed in one part of the North Atlantic went silent for an extended period starting soon after the onset of a seismic survey in the area (Clark and Gagnon 2006). It is not clear from that preliminary paper whether the whales ceased calling because of masking, or whether this was a behavioral response not directly involving masking. Also, bowhead whales in the Beaufort Sea may decrease their call rates in response to seismic operations, although movement out of the area might also have contributed to the lower call detection rate (Blackwell et al. 2009a,b). In contrast, Di Iorio and Clark (2009) found evidence of *increased* calling by blue whales during operations by a lower-energy seismic source—a sparker.

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

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

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

5. Disturbance by Seismic Surveys

Disturbance includes a variety of effects, including subtle to conspicuous changes in behavior, movement, and displacement. In the terminology of the 1994 amendments to the U.S. Marine Mammal

Protection Act (MMPA), seismic noise could cause "Level B" harassment of certain marine mammals. Level B harassment is defined as "...disruption of behavioral patterns, including, but not limited to, migration, breathing, nursing, breeding, feeding, or sheltering."

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

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

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

Even with this guidance, there are difficulties in defining what marine mammals should be counted as "taken by harassment". Available detailed data on reactions of marine mammals to airgun sounds (and other anthropogenic sounds) are limited to relatively few species and situations (see Richardson et al. 1995; Gordon et al. 2004; Nowacek et al. 2007; Southall et al. 2007). Behavioral reactions of marine mammals to sound are difficult to predict in the absence of site- and context-specific data. Reactions to sound, if any, depend on species, state of maturity, experience, current activity, reproductive state, time of day, and many other factors (Richardson et al. 1995; Wartzok et al. 2004; Southall et al. 2007; Weilgart 2007). If a marine mammal reacts to an underwater sound by changing its behavior or moving a small distance, the impacts of the change are unlikely to be significant to the individual, let alone the stock or population. However, if a sound source displaces marine mammals from an important feeding or breeding area for a prolonged period, impacts on individuals and populations could be significant (e.g., Lusseau and Bejder 2007; Weilgart 2007). Also, various authors have noted that some marine mammals that show no obvious avoidance or behavioral changes may still be adversely affected by noise (Brodie 1981; Richardson et al. 1995:317*ff*; Romano et al. 2004; Weilgart 2007; Wright et al. 2009). For example, some research suggests that animals in poor condition or in an already stressed state may not react as strongly to human disturbance as would more robust animals (e.g., Beale and Monaghan 2004).

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

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

The definitions of "taking" in the U.S. MMPA, and its applicability to various activities, were slightly altered in November 2003 for military and federal scientific research activities. Also, NMFS is proposing to replace current Level A and B harassment criteria with guidelines based on exposure characteristics that are specific to particular groups of mammal species and to particular sound types (NMFS 2005). Recently, a committee of specialists on noise impact issues has proposed new science-based impact criteria (Southall et al. 2007). Thus, for projects subject to U.S. jurisdiction, changes in procedures may be required in the near future.

The sound criteria used to estimate how many marine mammals might be disturbed to some biologically significant degree by seismic survey activities are primarily based on behavioral observations of a few species. Detailed studies have been done on humpback, gray, bowhead, and sperm whales, and on ringed seals. Less detailed data are available for some other species of baleen whales and small toothed whales, but for many species there are no data on responses to marine seismic surveys.

5.1 Baleen Whales

Baleen whales generally tend to avoid operating airguns, but avoidance radii are quite variable among species, locations, whale activities, oceanographic conditions affecting sound propagation, etc. (reviewed in Richardson et al. 1995; Gordon et al. 2004). Whales are often reported to show no overt reactions to pulses from large arrays of airguns at distances beyond a few kilometers, even though the airgun pulses remain well above ambient noise levels out to much longer distances. However, baleen whales exposed to strong sound pulses from airguns often react by deviating from their normal migration route and/or interrupting their feeding and moving away. Some of the major studies and reviews on this topic are Malme et al. (1984, 1985, 1988); Richardson et al. (1986, 1995, 1999); Ljungblad et al. (1988); Richardson and Malme (1993); McCauley et al. (1998, 2000a,b); Miller et al. (1999, 2005); Gordon et al. (2004); Moulton and Miller (2005); Stone and Tasker (2006); Johnson et al. (2007); Nowacek et al. (2007) and Weir (2008a). Although baleen whales often show only slight overt responses to operating airgun arrays (Stone and Tasker 2006; Weir 2008a), strong avoidance reactions by several species of mysticetes have been observed at ranges up to 6–8 km and occasionally as far as 20–30 km from the source vessel when large arrays of airguns were used. Experiments with a single airgun showed that bowhead, humpback and gray whales all showed localized avoidance to a single airgun of 20–100 in^3 (Malme et al. 1984, 1985, 1986, 1988; Richardson et al. 1986; McCauley et al. 1998, 2000a,b).

Studies of gray, bowhead, and humpback whales have shown that seismic pulses with received levels of 160–170 dB re 1 μPa (rms) seem to cause obvious avoidance behavior in a substantial portion of the animals exposed (Richardson et al. 1995). In many areas, seismic pulses from large arrays of airguns diminish to those levels at distances ranging from 4–15 km from the source. More recent studies have shown that some species of baleen whales (bowheads and humpbacks in particular) at times show strong avoidance at received levels lower than 160–170 dB re 1 μPa (rms). The largest avoidance radii involved migrating bowhead whales, which avoided an operating seismic vessel by 20–30 km (Miller et al. 1999; Richardson et al. 1999). In the cases of migrating bowhead (and gray) whales, the observed changes in behavior appeared to be of little or no biological consequence to the animals—they simply avoided the sound source by displacing their migration route to varying degrees, but within the natural boundaries of the migration corridors (Malme et al. 1984; Malme and Miles 1985; Richardson et al. 1995). Feeding bowhead whales, in contrast to migrating whales, show much smaller avoidance distances (Miller et al. 2005; Harris et al. 2007), presumably because moving away from a food concentration has greater cost to the whales than does a course deviation during migration.

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

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

Humpback whales on their summer feeding grounds in southeast Alaska did not exhibit persistent avoidance when exposed to seismic pulses from a 1.64-L (100 in^3) airgun (Malme et al. 1985). Some humpbacks seemed "startled" at received levels of 150–169 dB re 1 µPa (rms). Malme et al. (1985) concluded that there was no clear evidence of avoidance, despite the possibility of subtle effects, at received levels up to 172 re 1 µPa on an approximate rms basis.

Among wintering humpback whales off Angola (*n* = 52 useable groups), there were no significant differences in encounter rates (sightings/hr) when a 24-airgun array (3147 in^3 or 5085 in^3) was operating vs. silent (Weir 2008a). There was also no significant difference in the mean CPA (closest observed point of approach) distance of the humpback sightings when airguns were on vs. off (3050 m vs. 2700 m, respectively).

It has been suggested that South Atlantic humpback whales wintering off Brazil may be displaced or even strand upon exposure to seismic surveys (Engel et al. 2004). The evidence for this was circumstantial and subject to alternative explanations (IAGC 2004). Also, the evidence was not consistent with subsequent results from the same area of Brazil (Parente et al. 2006), or with direct studies of humpbacks exposed to seismic surveys in other areas and seasons (see above). After allowance for data from subsequent years, there was "no observable direct correlation" between strandings and seismic surveys (IWC 2007, p. 236).

Bowhead Whales.—Responsiveness of bowhead whales to seismic surveys can be quite variable depending on their activity (feeding vs. migrating). Bowhead whales on their summer feeding grounds in the Canadian Beaufort Sea showed no obvious reactions to pulses from seismic vessels at distances of 6–99 km and received sound levels of 107–158 dB on an approximate rms basis (Richardson et al. 1986); their general activities were indistinguishable from those of a control group. However, subtle but statistically significant changes in surfacing–respiration–dive cycles were evident upon statistical analysis. Bowheads usually did show strong avoidance responses when seismic vessels approached within a few kilometers (~3–7 km) and when received levels of airgun sounds were 152–178 dB (Richardson et al. 1986, 1995; Ljungblad et al. 1988; Miller et al. 2005). They also moved away when a single airgun fired nearby (Richardson et al. 1986; Ljungblad et al. 1988). In one case, bowheads engaged in near-bottom feeding began to turn away from a 30-airgun array with a source level of 248 dB re 1 µPa · m at a distance of 7.5 km, and swam away when it came within ~2 km; some whales continued feeding until the vessel was 3 km away (Richardson et al. 1986). This work and subsequent summer studies in the same region by Miller et al. (2005) and Harris et al. (2007) showed that many feeding bowhead whales tend to tolerate higher sound levels than migrating bowhead whales (see below) before showing an overt change in behavior. On the summer feeding grounds, bowhead whales are often seen from the operating seismic ship, though average sighting distances tend to be larger when the airguns are operating. Similarly, preliminary analyses of recent data from the Alaskan Beaufort Sea indicate that bowheads feeding there during late summer and autumn also did not display large-scale distributional changes in relation to seismic operations (Christie et al. 2009; Koski et al. 2009). However, some individual bowheads apparently begin to react at distances a few kilometers away, beyond the distance at which observers on the ship can sight bowheads (Richardson et al. 1986; Citta et al. 2007). The feeding whales may be affected by the sounds, but the need to feed may reduce the tendency to move away until the airguns are within a few kilometers.

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

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

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

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

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

There was no indication that western gray whales exposed to seismic noise were displaced from their overall feeding grounds near Sakhalin Island during seismic programs in 1997 (Würsig et al. 1999) and in 2001 (Johnson et al. 2007; Meier et al. 2007; Yazvenko et al. 2007a). However, there were indications of subtle behavioral effects among whales that remained in the areas exposed to airgun sounds (Würsig et al. 1999; Gailey et al. 2007; Weller et al. 2006a). Also, there was evidence of localized redistribution of some individuals within the nearshore feeding ground so as to avoid close approaches by the seismic vessel (Weller et al. 2002, 2006b; Yazvenko et al. 2007a). Despite the evidence of subtle changes in some quantitative measures of behavior and local redistribution of some individuals, there was no apparent change in the frequency of feeding, as evident from mud plumes visible at the surface (Yazvenko et al. 2007b). The 2001 seismic program involved an unusually comprehensive combination of real-time monitoring and mitigation measures designed to avoid exposing western gray whales to received levels of sound above about 163 dB re 1 μPa (rms) (Johnson et al. 2007). The lack of strong avoidance or other strong responses was presumably in part a result of the mitigation measures. Effects probably would have been more significant without such intensive mitigation efforts.

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

Rorquals.—Blue, sei, fin, and minke whales (all of which are members of the genus *Balaenoptera*) often have been seen in areas ensonified by airgun pulses (Stone 2003; MacLean and Haley 2004; Stone and Tasker 2006), and calls from blue and fin whales have been localized in areas with airgun operations (e.g., McDonald et al. 1995; Dunn and Hernandez 2009). Sightings by observers on seismic vessels during 110 large-source seismic surveys off the U.K. from 1997 to 2000 suggest that, during times of good sightability, sighting rates for mysticetes (mainly fin and sei whales) were similar when large arrays of airguns were shooting vs. silent (Stone 2003; Stone and Tasker 2006). However, these whales tended to exhibit localized avoidance, remaining significantly further (on average) from the airgun array during seismic operations compared with non-seismic periods ($P = 0.0057$; Stone and Tasker 2006). The average CPA distances for baleen whales sighted when large airgun arrays were operating vs. silent were about 1.6 vs. 1.0 km. Baleen whales, as a group, were more often oriented away from the vessel while a large airgun array was shooting compared with periods of no shooting ($P < 0.05$; Stone and Tasker 2006). In addition, fin/sei whales were less likely to remain submerged during periods of seismic shooting (Stone 2003).

In a study off Nova Scotia, Moulton and Miller (2005) found little difference in sighting rates (after accounting for water depth) and initial average sighting distances of balaenopterid whales when airguns were operating (mean = 1324 m) vs. silent (mean = 1303 m). However, there were indications that these whales were more likely to be moving away when seen during airgun operations. Baleen whales at the average sighting distance during airgun operations would have been exposed to sound levels (via direct path) of about 169 dB re 1 µPa (rms) (Moulton and Miller 2005). Similarly, ship-based monitoring studies of blue, fin, sei and minke whales offshore of Newfoundland (Orphan Basin and Laurentian Sub-basin) found no more than small differences in sighting rates and swim directions during seismic vs. non-seismic periods (Moulton et al. 2005, 2006a,b). Analyses of CPA data yielded variable results.[5] The authors of the Newfoundland reports concluded that, based on observations from the seismic vessel, some mysticetes exhibited localized avoidance of seismic operations (Moulton et al. 2005, 2006a).

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

Discussion and Conclusions.—Baleen whales generally tend to avoid operating airguns, but avoidance radii are quite variable. Whales are often reported to show no overt reactions to airgun pulses at distances beyond a few kilometers, even though the airgun pulses remain well above ambient noise levels out to much longer distances. However, studies done since the late 1990s of migrating humpback and migrating bowhead whales show reactions, including avoidance, that sometimes extend to greater distances than documented earlier. Avoidance distances often exceed the distances at which boat-based observers can see whales, so observations from the source vessel can be biased. Observations over broader areas may be needed to determine the range of potential effects of some large-source seismic

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

surveys where effects on cetaceans may extend to considerable distances (Richardson et al. 1999; Bain and Williams 2006; Moore and Angliss 2006). Longer-range observations, when required, can sometimes be obtained via systematic aerial surveys or aircraft-based observations of behavior (e.g., Richardson et al. 1986, 1999; Miller et al. 1999, 2005; Yazvenko et al. 2007a,b) or by use of observers on one or more support vessels operating in coordination with the seismic vessel (e.g., Smultea et al. 2004; Johnson et al. 2007). However, the presence of other vessels near the source vessel can, at least at times, reduce sightability of cetaceans from the source vessel (Beland et al. 2009), thus complicating interpretation of sighting data.

Some baleen whales show considerable tolerance of seismic pulses. However, when the pulses are strong enough, avoidance or other behavioral changes become evident. Because the responses become less obvious with diminishing received sound level, it has been difficult to determine the maximum distance (or minimum received sound level) at which reactions to seismic become evident and, hence, how many whales are affected.

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

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

Data on short-term reactions by cetaceans to impulsive noises are not necessarily indicative of long-term or biologically significant effects. It is not known whether impulsive sounds affect reproductive rate or distribution and habitat use in subsequent days or years. However, gray whales have continued to migrate annually along the west coast of North America despite intermittent seismic exploration (and much ship traffic) in that area for decades (Appendix A *in* Malme et al. 1984; Richardson et al. 1995), and there has been a substantial increase in the population over recent decades (Allen and Angliss 2011). The western Pacific gray whale population did not seem affected by a seismic survey in its feeding ground during a prior year (Johnson et al. 2007). Similarly, bowhead whales have continued to travel to the eastern Beaufort Sea each summer despite seismic exploration in their summer and autumn range for many years (Richardson et al. 1987), and their numbers have increased notably (Allen and Anglis 2010). Bowheads also have been observed over periods of days or weeks in areas ensonified repeatedly by seismic pulses (Richardson et al. 1987; Harris et al. 2007). However, it is generally not known whether the same individual bowheads were involved in these repeated observations (within and between years) in strongly ensonified areas. In any event, in the absence of some unusual circumstances, the history of coexistence between seismic surveys and baleen whales suggests that brief exposures to sound pulses from any single seismic survey are unlikely to result in prolonged effects.

5.2 Toothed Whales

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

Delphinids (Dolphins and similar) and Monodontids (Beluga).—Seismic operators and marine mammal observers on seismic vessels regularly see dolphins and other small toothed whales near operating airgun arrays, but in general there is a tendency for most delphinids to show some avoidance of operating seismic vessels (e.g., Goold 1996a,b,c; Calambokidis and Osmek 1998; Stone 2003; Moulton and Miller 2005; Holst et al. 2006; Stone and Tasker 2006; Weir 2008a; Richardson et al. 2009; see also Barkaszi et al. 2009). In most cases, the avoidance radii for delphinids appear to be small, on the order of 1 km or less, and some individuals show no apparent avoidance. Studies that have reported cases of small toothed whales close to the operating airguns include Duncan (1985), Arnold (1996), Stone (2003), and Holst et al. (2006). When a 3959 in^3, 18-airgun array was firing off California, toothed whales behaved in a manner similar to that observed when the airguns were silent (Arnold 1996). Some dolphins seem to be attracted to the seismic vessel and floats, and some ride the bow wave of the seismic vessel even when a large array of airguns is firing (e.g., Moulton and Miller 2005). Nonetheless, small toothed whales more often tend to head away, or to maintain a somewhat greater distance from the vessel, when a large array of airguns is operating than when it is silent (e.g., Stone and Tasker 2006; Weir 2008a).

Weir (2008b) noted that a group of short-finned pilot whales initially showed an avoidance response to ramp up of a large airgun array, but that this response was limited in time and space. Although the ramp-up procedure is a widely-used mitigation measure, it remains uncertain how effective it is at alerting marine mammals (especially odontocetes) and causing them to move away from seismic operations (Weir 2008b).

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

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

Observers stationed on seismic vessels operating off the U.K. from 1997 to 2000 have provided data on the occurrence and behavior of various toothed whales exposed to seismic pulses (Stone 2003; Gordon et al. 2004; Stone and Tasker 2006). Dolphins of various species often showed more evidence of avoidance of operating airgun arrays than has been reported previously for small odontocetes. Sighting rates of white-sided dolphins, white-beaked dolphins, *Lagenorhynchus* spp., and all small odontocetes combined were significantly lower during periods when large-volume[6] airgun arrays were shooting. Except for the pilot whale and bottlenose dolphin, CPA distances for all of the small odontocete species tested, including killer whales, were significantly farther from large airgun arrays during periods of shooting compared with periods of no shooting. Pilot whales were less responsive than other small odontocetes in the presence of seismic surveys (Stone and Tasker 2006). For small odontocetes as a group, and most individual species, orientations differed between times when large airgun arrays were operating vs. silent, with significantly fewer animals traveling towards and/or more traveling away from the vessel during shooting (Stone and Tasker 2006). Observers' records suggested that fewer cetaceans were feeding and fewer were interacting with the survey vessel (e.g., bow-riding) during periods with airguns operating, and small odontocetes tended to swim faster during periods of shooting (Stone and Tasker 2006). For most types of small odontocetes sighted by observers on seismic vessels, the median CPA distance was ≥0.5 km larger during airgun operations (Stone and Tasker 2006). Killer whales appeared to be more tolerant of seismic shooting in deeper waters.

Data collected during seismic operations in the Gulf of Mexico and off Central America show similar patterns. A summary of vessel-based monitoring data from the Gulf of Mexico during 2003–2008 showed that delphinids were generally seen farther from the vessel during seismic than during non-seismic periods (based on Barkaszi et al. 2009, excluding sperm whales). Similarly, during two NSF-funded L-DEO seismic surveys that used a large 20 airgun array (~7000 in^3), sighting rates of delphinids were lower and initial sighting distances were farther away from the vessel during seismic than non-seismic periods (Smultea et al. 2004; Holst et al. 2005a, 2006; Richardson et al. 2009). Monitoring results during a seismic survey in the Southeast Caribbean showed that the mean CPA of delphinids was 991 m during seismic operations vs. 172 m when the airguns were not operational (Smultea et al. 2004). Surprisingly, nearly all acoustic detections via a towed passive acoustic monitoring (PAM) array, including both delphinids and sperm whales, were made when the airguns were operating (Smultea et al. 2004). Although the number of sightings during monitoring of a seismic survey off the Yucatán Peninsula, Mexico, was small ($n = 19$), the results showed that the mean CPA distance of delphinids there was 472 m during seismic operations vs. 178 m when the airguns were silent (Holst et al. 2005a). The acoustic detection rates were nearly 5 times higher during non-seismic compared with seismic operations (Holst et al. 2005a).

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

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

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

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

Reactions of toothed whales to a single airgun or other small airgun source are not well documented, but tend to be less substantial than reactions to large airgun arrays (e.g., Stone 2003; Stone and Tasker 2006). During 91 site surveys off the U.K. in 1997–2000, sighting rates of all small odontocetes combined were significantly lower during periods the low-volume[7] airgun sources were operating, and effects on orientation were evident for all species and groups tested (Stone and Tasker 2006). Results from four NSF-funded L-DEO seismic surveys using small arrays (up to 3 GI guns and 315 in^3) were inconclusive. During surveys in the Eastern Tropical Pacific (Holst et al. 2005b) and in the Northwest Atlantic (Haley and Koski 2004), detection rates were slightly lower during seismic compared to non-seismic periods. However, mean CPAs were closer during seismic operations during one cruise (Holst et al. 2005b), and greater during the other cruise (Haley and Koski 2004). Interpretation of the data was confounded by the fact that survey effort and/or number of sightings during non-seismic periods during both surveys was small. Results from another two small-array surveys were even more variable (MacLean and Koski 2005; Smultea and Holst 2008).

Captive bottlenose dolphins and beluga whales exhibited changes in behavior when exposed to strong pulsed sounds similar in duration to those typically used in seismic surveys (Finneran et al. 2000, 2002, 2005). Finneran et al. (2002) exposed a captive bottlenose dolphin and beluga to single impulses from a water gun (80 in^3). As compared with airgun pulses, water gun impulses were expected to contain proportionally more energy at higher frequencies because there is no significant gas-filled bubble, and thus little low-frequency bubble-pulse energy (Hutchinson and Detrick 1984). The captive animals sometimes vocalized after exposure and exhibited reluctance to station at the test site where subsequent exposure to impulses would be implemented (Finneran et al. 2002). Similar behaviors were exhibited by captive bottlenose dolphins and a beluga exposed to single underwater pulses designed to simulate those produced by distant underwater explosions (Finneran et al. 2000). It is uncertain what relevance these observed behaviors in captive, trained marine mammals exposed to single transient sounds may have to

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[7] For low volume arrays, maximum volume was 820 in^3, with most (87%) $\leq$180 in^3.

free-ranging animals exposed to multiple pulses. In any event, the animals tolerated rather high received levels of sound before exhibiting the aversive behaviors mentioned above.

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

Phocoenids (Porpoises).—Porpoises, like delphinids, show variable reactions to seismic operations, and reactions apparently depend on species. The limited available data suggest that harbor porpoises show stronger avoidance of seismic operations than Dall’s porpoises (Stone 2003; MacLean and Koski 2005; Bain and Williams 2006). In Washington State waters, the harbor porpoise—despite being considered a high-frequency specialist—appeared to be the species affected by the lowest received level of airgun sound (<145 dB re 1 μPa (rms) at a distance >70 km; Bain and Williams 2006). Similarly, during seismic surveys with large airgun arrays off the U.K. in 1997–2000, there were significant differences in directions of travel by harbor porpoises during periods when the airguns were shooting vs. silent (Stone 2003; Stone and Tasker 2006). A captive harbor porpoise exposed to single sound pulses from a small airgun showed aversive behavior upon receipt of a pulse with received level above 174 dB re 1 $\mu Pa_{pk\text{-}pk}$ or SEL >145 dB re 1 $\mu Pa^2 \cdot s$ (Lucke et al. 2009). In contrast, Dall’s porpoises seem relatively tolerant of airgun operations (MacLean and Koski 2005; Bain and Williams 2006), although they too have been observed to avoid large arrays of operating airguns (Calambokidis and Osmek 1998; Bain and Williams 2006). The apparent tendency for greater responsiveness in the harbor porpoise is consistent with their relative responsiveness to boat traffic and some other acoustic sources (Richardson et al. 1995; Southall et al. 2007).

Beaked Whales.—There are almost no specific data on the behavioral reactions of beaked whales to seismic surveys. Most beaked whales tend to avoid approaching vessels of other types (e.g., Würsig et al. 1998). They may also dive for an extended period when approached by a vessel (e.g., Kasuya 1986), although it is uncertain how much longer such dives may be as compared to dives by undisturbed beaked whales, which also are often quite long (Baird et al. 2006; Tyack et al. 2006b). In any event, it is likely that most beaked whales would also show strong avoidance of an approaching seismic vessel, regardless of whether or not the airguns are operating. However, this has not been documented explicitly. Northern bottlenose whales sometimes are quite tolerant of slow-moving vessels not emitting airgun pulses (Reeves et al. 1993; Hooker et al. 2001). The few detections (acoustic or visual) of northern bottlenose whales from seismic vessels during recent seismic surveys off Nova Scotia have been during times when the airguns were shut down; no detections were reported when the airguns were operating (Moulton and Miller 2005; Potter et al. 2007). However, other visual and acoustic studies indicated that some northern bottlenose whales remained in the general area and continued to produce high-frequency clicks when exposed to sound pulses from distant seismic surveys (Gosselin and Lawson 2004; Laurinolli and Cochrane 2005; Simard et al. 2005).

There are increasing indications that some beaked whales tend to strand when military exercises involving mid-frequency sonar operation are ongoing nearby (e.g., Simmonds and Lopez-Jurado 1991; Frantzis 1998; NOAA and USN 2001; Jepson et al. 2003; Barlow and Gisiner 2006; see also the “Strandings and Mortality” subsection, later). These strandings are apparently at least in part a disturbance response, although auditory or other injuries or other physiological effects may also be a factor. Whether beaked whales would ever react similarly to seismic surveys is unknown. Seismic survey sounds are quite different from those of the sonars in operation during the above-cited incidents. No conclusive link has been established between seismic surveys and beaked whale strandings. There was a stranding of two Cuvier’s beaked whales in the Gulf of California (Mexico) in September 2002 when the R/V *Maurice Ewing* was conducting a seismic survey in the general area (e.g., Malakoff 2002; Hildebrand 2005). However, NMFS did not establish a cause and effect relationship between this stranding and the seismic survey activities (Hogarth 2002). Cox et al. (2006) noted the “lack of knowledge regarding the temporal and spatial correlation between the [stranding] and the sound source”. Hildebrand (2005) illustrated the approximate temporal-spatial relationships between the stranding and the *Ewing*’s tracks, but the time of the stranding was not known with sufficient precision for accurate determination of the CPA distance of the whales to the *Ewing*. Another stranding of Cuvier’s beaked whales in the Galápagos occurred during a seismic survey in April 2000; however “There is no obvious mechanism that bridges the distance between this source and the stranding site” (Gentry [ed.] 2002).

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

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

Recent and more extensive data from vessel-based monitoring programs in U.K. waters and off Newfoundland and Angola suggest that sperm whales in those areas show little evidence of avoidance or behavioral disruption in the presence of operating seismic vessels (Stone 2003; Stone and Tasker 2006; Moulton et al. 2005, 2006a; Weir 2008a). Among sperm whales off Angola (n = 96 useable groups), there were no significant differences in encounter rates (sightings/hr) when a 24-airgun array (3147 in^3 or 5085 in^3) was operating vs. silent (Weir 2008a). There was also no significant difference in the CPA distances of the sperm whale sightings when airguns were on vs. off (means 3039 m vs. 2594 m, respectively). Encounter rate tended to increase over the 10-month duration of the seismic survey. These types of observations are difficult to interpret because the observers are stationed on or near the seismic vessel, and may underestimate reactions by some of the more responsive animals, which may be beyond visual range. However, these results do seem to show considerable tolerance of seismic surveys by at least some sperm whales. Also, a study off northern Norway indicated that sperm whales continued to call when exposed to pulses from a distant seismic vessel. Received levels of the seismic pulses were up to 146 dB re 1 $\mu Pa_{p\text{-}p}$ (Madsen et al. 2002).

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

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

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

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

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

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

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

5.3 Pinnipeds

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

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

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

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

Monitoring work in the Alaskan Beaufort Sea during 1996–2001 provided considerable information regarding the behavior of seals exposed to seismic pulses (Harris et al. 2001; Moulton and Lawson 2002). Those seismic projects usually involved arrays of 6–16 airguns with total volumes 560–1500 in^3. Subsequent monitoring work in the Canadian Beaufort Sea in 2001–2002, with a somewhat larger airgun system (24 airguns, 2250 in^3), provided similar results (Miller et al. 2005). The combined results suggest that some seals avoid the immediate area around seismic vessels. In most survey years, ringed seal sightings averaged somewhat farther away from the seismic vessel when the airguns were operating than when they were not (Moulton and Lawson 2002). Also, seal sighting rates at the water surface were lower during airgun array operations than during no-airgun periods in each survey year except 1997. However, the avoidance movements were relatively small, on the order of 100 m to (at most) a few hundreds of meters, and many seals remained within 100–200 m of the trackline as the operating airgun array passed by.

The operation of the airgun array had minor and variable effects on the behavior of seals visible at the surface within a few hundred meters of the airguns (Moulton and Lawson 2002). The behavioral data indicated that some seals were more likely to swim away from the source vessel during periods of airgun operations and more likely to swim towards or parallel to the vessel during non-seismic periods. No consistent relationship was observed between exposure to airgun noise and proportions of seals engaged in other recognizable behaviors, e.g., "looked" and "dove". Such a relationship might have occurred if seals seek to reduce exposure to strong seismic pulses, given the reduced airgun noise levels close to the surface where "looking" occurs (Moulton and Lawson 2002).

Monitoring results from the Canadian Beaufort Sea during 2001–2002 were more variable (Miller et al. 2005). During 2001, sighting rates of seals (mostly ringed seals) were similar during all seismic states, including periods without airgun operations. However, seals tended to be seen closer to the vessel during non-seismic than seismic periods. In contrast, during 2002, sighting rates of seals were higher during non-seismic periods than seismic operations, and seals were seen farther from the vessel during non-seismic compared to seismic activity (a marginally significant result). The combined data for both years showed that sighting rates were higher during non-seismic periods compared to seismic periods, and that sighting distances were similar during both seismic states. Miller et al. (2005) concluded that seals showed very limited avoidance to the operating airgun array.

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

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

5.4 Sirenians, Sea Otter and Polar Bear

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

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

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

6. Hearing Impairment and Other Physical Effects of Seismic Surveys

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

- the 180-dB criterion for cetaceans is probably quite precautionary, i.e., lower than necessary to avoid temporary auditory impairment let alone permanent auditory injury, at least for delphinids.
- TTS is not injury and does not constitute “Level A harassment” in U.S. MMPA terminology.

- the minimum sound level necessary to cause permanent hearing impairment ("Level A harassment") is higher, by a variable and generally unknown amount, than the level that induces barely-detectable TTS.
- the level associated with the onset of TTS is often considered to be a level below which there is no danger of permanent damage. The actual PTS threshold is likely to be well above the level causing onset of TTS (Southall et al. 2007).

Recommendations for new science-based noise exposure criteria for marine mammals, frequency-weighting procedures, and related matters were published recently (Southall et al. 2007). Those recommendations have not, as of late 2009, been formally adopted by NMFS for use in regulatory processes and during mitigation programs associated with seismic surveys. However, some aspects of the recommendations have been taken into account in certain EISs and small-take authorizations. NMFS has indicated that it may issue new noise exposure criteria for marine mammals that account for the now-available scientific data on TTS, the expected offset between the TTS and PTS thresholds, differences in the acoustic frequencies to which different marine mammal groups are sensitive, and other relevant factors. Preliminary information about possible changes in the regulatory and mitigation requirements, and about the possible structure of new criteria, was given by Wieting (2004) and NMFS (2005).

Several aspects of the monitoring and mitigation measures that are now often implemented during seismic survey projects are designed to detect marine mammals occurring near the airgun array, and to avoid exposing them to sound pulses that might, at least in theory, cause hearing impairment. In addition, many cetaceans and (to a limited degree) pinnipeds show some avoidance of the area where received levels of airgun sound are high enough such that hearing impairment could potentially occur. In those cases, the avoidance responses of the animals themselves will reduce or (most likely) avoid the possibility of hearing impairment.

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

6.1 Temporary Threshold Shift (TTS)

TTS is the mildest form of hearing impairment that can occur during exposure to a strong sound (Kryter 1985). While experiencing TTS, the hearing threshold rises and a sound must be stronger in order to be heard. It is a temporary phenomenon, and (especially when mild) is not considered to represent physical damage or "injury" (Southall et al. 2007). Rather, the onset of TTS is an indicator that, if the animal is exposed to higher levels of that sound, physical damage is ultimately a possibility.

The magnitude of TTS depends on the level and duration of noise exposure, and to some degree on frequency, among other considerations (Kryter 1985; Richardson et al. 1995; Southall et al. 2007). For sound exposures at or somewhat above the TTS threshold, hearing sensitivity recovers rapidly after exposure to the noise ends. In terrestrial mammals, TTS can last from minutes or hours to (in cases of strong TTS) days. Only a few data have been obtained on sound levels and durations necessary to elicit mild TTS in marine mammals (none in mysticetes), and none of the published data concern TTS elicited by exposure to multiple pulses of sound during operational seismic surveys (Southall et al. 2007).

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

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

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

On the other hand, the TTS threshold for odontocetes exposed to a single impulse from a watergun (Finneran et al. 2002) appeared to be somewhat lower than for exposure to non-impulse sound. This was expected, based on evidence from terrestrial mammals showing that broadband pulsed sounds with rapid rise times have greater auditory effect than do non-impulse sounds (Southall et al. 2007). The received energy level of a single seismic pulse that caused the onset of mild TTS in the beluga, as measured without frequency weighting, was ~186 dB re 1 $\mu Pa^2 \cdot s$ or 186 dB SEL (Finneran et al. 2002).[8] The rms level of an airgun pulse (in dB re 1 μPa measured over the duration of the pulse) is typically 10–15 dB higher than the SEL for the same pulse when received within a few kilometers of the airguns. Thus, a single airgun pulse might need to have a received level of ~196–201 dB re 1 μPa (rms) in order to produce brief, mild TTS. Exposure to several strong seismic pulses that each has a flat-weighted received level near 190 dB (rms) (175–180 dB SEL) could result in cumulative exposure of ~186 dB SEL (flat-weighted) or ~183 dB SEL (M_{mf}-weighted), and thus slight TTS in a small odontocete. That assumes that

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

the TTS threshold upon exposure to multiple pulses is (to a first approximation) a function of the total received pulse energy, without allowance for any recovery between pulses.

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

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

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

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

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

Pinnipeds.—In pinnipeds, TTS thresholds associated with exposure to brief pulses (single or multiple) of underwater sound have not been measured. Two California sea lions did not incur TTS when exposed to single brief pulses with received levels of ~178 and 183 dB re 1 µPa (rms) and total energy fluxes of 161 and 163 dB re 1 $\mu Pa^2 \cdot s$ (Finneran et al. 2003). However, initial evidence from more prolonged (non-pulse) exposures suggested that some pinnipeds (harbor seals in particular) incur TTS at somewhat lower received levels than do small odontocetes exposed for similar durations (Kastak et al. 1999, 2005; Ketten et al. 2001). Kastak et al. (2005) reported that the amount of threshold shift increased with increasing SEL in a California sea lion and harbor seal. They noted that, for non-impulse sound, doubling the exposure duration from 25 to 50 min (i.e., a +3 dB change in SEL) had a greater effect on TTS than an increase of 15 dB (95 vs. 80 dB) in exposure level. Mean threshold shifts ranged from 2.9–12.2 dB, with full recovery within 24 hr (Kastak et al. 2005). Kastak et al. (2005) suggested that, for non-impulse sound, SELs resulting in TTS onset in three species of pinnipeds may range from 183 to 206 dB re 1 $\mu Pa^2 \cdot s$, depending on the absolute hearing sensitivity.

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

At least for non-impulse sounds, TTS onset occurs at appreciably higher received levels in California sea lions and northern elephant seals than in harbor seals (Kastak et al. 2005). Thus, the former two species would presumably need to be closer to an airgun array than would a harbor seal before TTS is a possibility. Insofar as we are aware, there are no data to indicate whether the TTS thresholds of other pinniped species are more similar to those of the harbor seal or to those of the two less-sensitive species.

***Sirenians, Sea Otter and Polar Bear*.—**There are no available data on TTS in sea otters and polar bears. However, TTS is unlikely to occur in sea otters or polar bears if they are on the water surface, given the pressure release and Lloyd's mirror effects at the water's surface. Furthermore, sea otters tend to inhabit shallow coastal habitats where large seismic survey vessels towing large spreads of streamers may be unable to operate. TTS is also considered unlikely to occur in sirenians as a result of exposure to sounds from a seismic survey. They, like sea otters, tend to inhabit shallow coastal habitats and rarely range far from shore, whereas seismic survey vessels towing large arrays of airguns and (usually) even larger arrays of streamers normally must remain farther offshore because of equipment clearance and maneuverability limitations. Exposures of sea otters and sirenians to seismic surveys are more likely to involve smaller seismic sources that can be used in shallow and confined waters. The impacts of these are inherently less than would occur from a larger source of the types often used farther offshore.

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

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

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

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

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

6.2 Permanent Threshold Shift (PTS)

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

There is no specific evidence that exposure to pulses of airgun sound can cause PTS in any marine mammal, even with large arrays of airguns. However, given the likelihood that some mammals close to an airgun array might incur at least mild TTS (see above), there has been further speculation about the possibility that some individuals occurring very close to airguns might incur PTS (e.g., Richardson et al. 1995, p. 372*ff*; Gedamke et al. 2008). Single or occasional occurrences of mild TTS are not indicative of permanent auditory damage, but repeated or (in some cases) single exposures to a level well above that causing TTS onset might elicit PTS.

Relationships between TTS and PTS thresholds have not been studied in marine mammals, but are assumed to be similar to those in humans and other terrestrial mammals (Southall et al. 2007). Based on data from terrestrial mammals, a precautionary assumption is that the PTS threshold for impulse sounds (such as airgun pulses as received close to the source) is <u>at least</u> 6 dB higher than the TTS threshold on a peak-pressure basis, and probably >6 dB higher (Southall et al. 2007). The low-to-moderate levels of TTS that have been induced in captive odontocetes and pinnipeds during controlled studies of TTS have been confirmed to be temporary, with no measurable residual PTS (Kastak et al. 1999; Schlundt et al. 2000; Finneran et al. 2002, 2005; Nachtigall et al. 2003, 2004). However, very prolonged exposure to sound strong enough to elicit TTS, or shorter-term exposure to sound levels well above the TTS threshold, can cause PTS, at least in terrestrial mammals (Kryter 1985). In terrestrial mammals, the received sound level from a single non-impulsive sound exposure must be far above the TTS threshold for any risk of permanent hearing damage (Kryter 1994; Richardson et al. 1995; Southall et al. 2007). However, there is special concern about strong sounds whose pulses have very rapid rise times. In terrestrial mammals, there are situations when pulses with rapid rise times (e.g., from explosions) can result in PTS even though their peak levels are only a few dB higher than the level causing slight TTS. The rise time of airgun pulses is fast, but not as fast as that of an explosion.

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

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

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

More recently, Southall et al. (2007) estimated that received levels would need to exceed the TTS threshold by at least 15 dB, on an SEL basis, for there to be risk of PTS. Thus, for cetaceans exposed to a sequence of sound pulses, they estimate that the PTS threshold might be an M-weighted SEL (for the sequence of received pulses) of ~198 dB re 1 μPa$^2 \cdot$s (15 dB higher than the M_{mf}-weighted TTS threshold, in a beluga, for a watergun impulse). Additional assumptions had to be made to derive a corresponding estimate for pinnipeds, as the only available data on TTS-thresholds in pinnipeds pertained to non-impulse sound (see above). Southall et al. (2007) estimated that the PTS threshold could be a cumulative M_{pw}-weighted SEL of ~186 dB re 1 μPa$^2 \cdot$s in the case of a harbor seal exposed to impulse sound. The PTS threshold for the California sea lion and northern elephant seal would probably be higher given the higher TTS thresholds in those species. Southall et al. (2007) also note that, regardless of the SEL, there is concern about the possibility of PTS if a cetacean or pinniped received one or more pulses with peak pressure exceeding 230 or 218 dB re 1 μPa, respectively. Thus, PTS might be expected upon exposure of cetaceans to <u>either</u> SEL ≥198 dB re 1 μPa$^2 \cdot$s <u>or</u> peak pressure ≥230 dB re 1 μPa. Corresponding proposed dual criteria for pinnipeds (at least harbor seals) are ≥186 dB SEL and ≥ 218 dB peak pressure (Southall et al. 2007). These estimates are all first approximations, given the limited underlying data, assumptions, species differences, and evidence that the "equal energy" model is not be entirely correct.

Sound impulse duration, peak amplitude, rise time, number of pulses, and inter-pulse interval are the main factors thought to determine the onset and extent of PTS. Ketten (1994) has noted that the criteria for differentiating the sound pressure levels that result in PTS (or TTS) are location and species-specific. PTS effects may also be influenced strongly by the health of the receiver's ear.

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

The TTS section (above) concludes that exposure to several strong seismic pulses that each have flat-weighted received levels near 190 dB re 1 μPa (rms) (175–180 dB re 1 μPa$^2 \cdot$s SEL) could result in cumulative exposure of ~186 dB SEL (flat-weighted) or ~183 dB SEL (M_{mf}-weighted), and thus slight TTS in a small odontocete. Allowing for the assumed 15 dB offset between PTS and TTS thresholds, expressed on an SEL basis, exposure to several strong seismic pulses that each have flat-weighted received levels near 205 dB (rms) (190–195 dB SEL) could result in cumulative exposure of ~198 dB SEL (M_{mf}-weighted), and thus slight PTS in a small odontocete. However, the levels of successive pulses that will be received by a marine mammal that is below the surface as a seismic vessel approaches, passes and moves away will tend to increase gradually and then decrease gradually, with periodic decreases superimposed on this pattern when the animal comes to the surface to breathe. To estimate how close an odontocete's CPA distance would have to be for the cumulative SEL to exceed 198 dB SEL (M_{mf}-weighted), one would (as a minimum) need to allow for the sequence of distances at which airgun shots would occur, and for the dependence of received SEL on distance in the region of the seismic operation (e.g., Erbe and King 2009).

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

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

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

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

6.3 Strandings and Mortality

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

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

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

There is no conclusive evidence of cetacean strandings or deaths at sea as a result of exposure to seismic surveys, but a few cases of strandings in the general area where a seismic survey was ongoing have led to speculation concerning a possible link between seismic surveys and strandings. • Suggestions that there was a link between seismic surveys and strandings of humpback whales in Brazil (Engel et al. 2004) were not well founded (IAGC 2004; IWC 2007). • In Sept. 2002, there was a stranding of two Cuvier's beaked whales in the Gulf of California, Mexico, when the L-DEO seismic vessel R/V *Maurice Ewing* was operating a 20-airgun, 8490-in^3 airgun array in the general area. The evidence linking the stranding to the seismic survey was inconclusive and not based on any physical evidence (Hogarth 2002; Yoder 2002). The ship was also operating its multibeam echosounder at the same time, but this had much less potential than the aforementioned naval sonars to affect beaked whales, given its downward-directed beams, much shorter pulse durations, and lower duty cycle. Nonetheless, the Gulf of California incident plus the beaked whale strandings near naval exercises involving use of mid-frequency sonar suggest a need for caution in conducting seismic surveys in areas occupied by beaked whales until more is known about effects of seismic surveys on those species (Hildebrand 2005).

6.4 Non-Auditory Physiological Effects

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

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

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

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

7. Literature Cited

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

Allen, B.M., and R.P. Angliss. 2010. Alaska Marine Mammal Stock Assessments, 2009. NOAA Technical Memorandum NMFS-AFSC-206, 276 p.

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

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. from Impact Sciences Inc., San Diego, CA, for Exxon Co., 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 Handbook of Auditory Res. Vol. 12. Springer-Verlag, New York, NY. 458 p.

Au, W.W.L., A.A. Pack, M.O. Lammers, L.M. Herman, M.H. Deakos, and K. Andrews. 2006. Acoustic properties of humpback whale songs. **J. Acoust. Soc. Am.** 120(2):1103-1110.

Backus, R.H. and W.E. Schevill. 1966. *Physeter* clicks. p. 510-528 in K.S. Norris (ed.), Whales, dolphins, and porpoises. Univ. Calif. Press, Berkeley, CA. 789 p

Bain, D.E. and R. Williams. 2006. Long-range effects of airgun noise on marine mammals: responses as a function of received sound level and distance. Paper SC/58/E35 presented to the IWC Scient. Commit., IWC Annu. Meet., 1-13 June, St. Kitts.

Baird, R.W. 2005. Sightings of dwarf (*Kogia sima*) and pygmy (*K. breviceps*) sperm whales from the main Hawaiian Islands. **Pacific Sci.** 59(3):461-466.

Baird, R.W., D.L. Webster, D.J. McSweeney, A.D. Ligon, G.S. Schorr, and J. Barlow. 2006. Diving behavior and ecology of Cuvier's (*Ziphius cavirostris*) and Blainville's (*Mesoplodon densirostris*) beaked whales in Hawaii. **Can. J. Zool.** 84(8):1120-1128.

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.

Barkaszi, M.J., D.M. Epperson, and B. Bennett. 2009. Six-year compilation of cetacean sighting data collected during commercial seismic survey mitigation observations throughout the Gulf of Mexico, USA. p. 24-25 *In*: Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Canada, Oct. 2009. 306 p.

Barlow, J. and R. Gisiner. 2006. Mitigating, monitoring and assessing the effects of anthropogenic sound on beaked whales. **J. Cetac. Res. Manage.** 7(3):239-249.

Bauer, G.B., J.C. Gaspard, K. Dziuk, A. Cardwell, L. Read, R.L. Reep, and D.A. Mann. 2009. The manatee audiogram and auditory critical ratios. p. 27-28 *In*: Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Canada, Oct. 2009. 306 p.

Beale, C.M. and P. Monaghan. 2004. Behavioural responses to human disturbance: a matter of choice? **Anim. Behav.** 68(5):1065-1069.

Beland, J.A., B. Haley, C.M. Reiser, D.M. Savarese, D.S. Ireland and D.W. Funk. 2009. Effects of the presence of other vessels on marine mammal sightings during multi-vessel operations in the Alaskan Chukchi Sea. p. 29 *In*: Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Oct. 2009:29. 306 p.

Berta, A., R. Racicot and T. Deméré. 2009. The comparative anatomy and evolution of the ear in *Balaenoptera* mysticetes. p. 33 *In*: Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Oct. 2009. 306 p.

Blackwell, S.B., R.G. Norman, C.R. Greene Jr., and W.J. Richardson. 2007. Acoustic measurements. p. 4-1 to 4-52 *In:* Marine mammal monitoring and mitigation during open water seismic exploration by Shell Offshore Inc. in the Chukchi and Beaufort Seas, July-September 2006: 90-day report. LGL Rep. P891-1. Rep. from LGL Alaska Res. Assoc. Inc., Anchorage, AK, and Greeneridge Sciences Inc., Santa Barbara, CA, for Shell Offshore Inc., Houston, TX, Nat. Mar. Fish. Serv., Silver Spring, MD, and U.S. Fish & Wildl. Serv., Anchorage, AK. 199 p.

Blackwell, S.B., C.R. Greene, T.L. McDonald, C.S. Nations, R.G. Norman, and A. Thode. 2009a. Beaufort Sea bowhead whale migration route study. Chapter 8 *In*: D.S. Ireland, D.W. Funk, R. Rodrigues, and W.R. Koski (eds.). 2009. Joint Monitoring Program in the Chukchi and Beaufort seas, open water seasons, 2006-2007. LGL Alaska Rep. P971-2. Rep. from LGL Alaska Res. Assoc. Inc. (Anchorage, AK) et al. for Shell Offshore Inc. (Anchorage, AK) et al. 485 p. plus appendices.

Blackwell, S.B., C.S. Nations, T.L. McDonald, A.M. Thode, K.H. Kim, C.R. Greene, and M.A. Macrander. 2009b. Effects of seismic exploration activities on the calling behavior of bowhead whales in the Alaskan Beaufort Sea. p. 35 *In*: Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Canada, 12-16 Oct. 2009. 306 p.

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.Bullock, T.H., T.J. Oshea, and M.C. McClune. 1982. Auditory evoked-potentials in the West Indian manatee (Sirenia, *Trichechus manatus*). **J. Comp. Physiol.** 148(4):547-554.

Britto, M.K. and A. Silva Barreto. 2009. Marine mammal diversity registered on seismic surveys in Brazil, between 2000 and 2008. p. 41 *In*: Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Oct. 2009. 306 p.

Brodie, P.F. 1981. Energetic and behavioural considerations with respect to marine mammals and disturbance from underwater noise. p. 287-290 *In*: N.M. Peterson (ed.), The question of sound from icebreaker operations: Proceedings of a workshop. Arctic Pilot Proj., Petro-Canada, Calgary, Alb. 350 p.

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 Greeneridge Sciences Inc., Santa Barbara, CA, for Western Geophysical, Houston, TX, and 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. Rep. from Cascadia Res., 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. **Leading Edge** 19(8):898-902.

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

Christie, K., C. Lyons, W.R. Koski, D.S. Ireland, and D.W. Funk. 2009. Patterns of bowhead whale occurrence and distribution during marine seismic operations in the Alaskan Beaufort Sea. p. 55 *In*: Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Canada, 12-16 Oct. 2009.

Citta, J.J., L.T. Quakenbush, R.J. Small, and J.C. George. 2007. Movements of a tagged bowhead whale in the vicinity of a seismic survey in the Beaufort Sea. Poster Paper, Soc. Mar. Mammal. 17th Bienn. Meet., Cape Town, South Africa.

Clark, C.W. and W.T. Ellison. 2004. Potential use of low-frequency sounds by baleen whales for probing the environment: Evidence from models and empirical measurements. p. 564-589 *In:* J.A. Thomas, C.F. Moss and M. Vater (eds.), Echolocation in Bats and Dolphins. Univ. Chicago Press, Chicago, IL. 604 p.

Clark, C.W. and G.C. Gagnon. 2006. Considering the temporal and spatial scales of noise exposures from seismic surveys on baleen whales. Intern. Whal. Commis. Working Pap. SC/58/E9. 9 p.

Cook, M.L.H., R.A. Varela, J.D. Goldstein, S.D. McCulloch, G.D. Bossart, J.J. Finneran, D. Houser, and A. Mann. 2006. Beaked whale auditory evoked potential hearing measurements. **J. Comp. Physiol.** A 192:489-495.

Cox, T.M., T.J. Ragen, A.J. Read, E. Vos, R.W. Baird, K. Balcomb, J. Barlow, J. Caldwell, T. Cranford, L. Crum, A. D'Amico, G. D'Spain, A. Fernández, J. Finneran, R. Gentry, W. Gerth, F. Gulland, J. Hildebrand, D. Houserp, R. Hullar, P.D. Jepson, D. Ketten, C.D. Macleod, P. Miller, S. Moore, D.C. Mountain, D. Palka, P. Ponganis, S. Rommel, T. Rowles, B. Taylor, P. Tyack, D. Wartzok, R. Gisiner, J. Meads, and L. Benner. 2006. Understanding the impacts of anthropogenic sound on beaked whales. **J. Cetac. Res. Manage.** 7(3):177-187.

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. **Acoustic Res. Lett. Online** 6(3):214-220.

Dahlheim, M.E. 1987. Bio-acoustics of the gray whale (*Eschrichtius robustus*). Ph.D. Dissertation, Univ. British Columbia, Vancouver, BC. 315 p.

DeRuiter, S.L., P.L. Tyack, Y.-T. Lin, A.E. Newhall, J.F. Lynch, and P.J.O. Miller. 2006. Modeling acoustic propagation of airgun array pulses recorded on tagged sperm whales (*Physeter macrocephalus*). **J. Acoust. Soc. Am.** 120(6):4100-4114.

Di Iorio, L. and C.W. Clark. 2009. Exposure to seismic survey alters blue whale acoustic communication. **Biol. Lett.** doi: 10.1098/rsbl.2009.0651.

Dolman, S.J. and M.P. Simmonds. 2006. An updated note on the vulnerability of cetaceans to acoustic disturbance. Paper SC/58/E22 presented to the IWC Scient. Commit., IWC Annu. Meet., 1-13 June, St. Kitts.

Duncan, P.M. 1985. Seismic sources in a marine environment. p. 56-88 *In:* Proceedings of the 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. Branch, Ottawa, Ont.

Dunn, R.A. and O. Hernandez. 2009. Tracking blue whales in the eastern tropical Pacific with an ocean-bottom seismometer and hydrophone array. **J. Acoust. Soc. Am.** 126(3):1084-1094.

Engel, M.H., M.C.C. Marcondes, C.C.A. Martins, F.O. Luna, R.P. Lima, and A. Campos. 2004. Are seismic surveys responsible for cetacean strandings? An unusual mortality of adult humpback whales in Abrolhos Bank, northeastern coast of Brazil. Paper SC/56/E28 presented to the IWC Scient. Commit., IWC Annu. Meet., 19-22 July, Sorrento, Italy.

Erbe, C. and A.R. King. 2009. Modeling cumulative sound exposure around marine seismic surveys. **J. Acoust. Soc. Am.** 125(4):2443-2451.

Fair, P.A. and P.R. Becker. 2000. Review of stress in marine mammals. **J. Aquat. Ecosyst. Stress Recov.** 7:335-354.

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, 15 Apr.). doi: 10.1038/nature02528a.

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

Finneran, J.J. and C.E. Schlundt. 2004. Effects of intense pure tones on the behavior of trained odontocetes. Tech. Rep. 1913. Space and Naval Warfare (SPAWAR) Systems Center, San Diego, CA. 15 p.

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., 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.

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

Finneran, J.J., D.S. Houser, B. Mase-Guthrie, R.Y. Ewing and R.G. Lingenfelser. 2009. Auditory evoked potentials in a stranded Gervais' beaked whale (*Mesoplodon europaeus*). **J. Acoust. Soc. Am.** 126(1):484-490.

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 (Abstract).

Frankel, A. 2005. Gray whales hear and respond to a 21-25 kHz high-frequency whale-finding sonar. p. 97 *In*: Abstr. 16th Bienn. Conf. Biol. Mar. Mamm., San Diego, CA, Dec. 2005. 306 p.

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. p. 187-200 *In:* B.R. Melteff and D.H. Rosenberg (eds.), Proceedings of the 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.

Gabriele, C.M. and B. Kipple. 2009. Measurements of near-surface, near-bow underwater sound from cruise ships. p. 86 *In*: Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Oct. 2009. 306 p.

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

Gedamke, J., S. Frydman, and N. Gales. 2008. Risk of baleen whale hearing loss from seismic surveys: preliminary results from simulations accounting for uncertainty and individual variation. Intern. Whal. Comm. Working Pap. SC/60/E9. 10 p.

Gentry, R. (ed.). 2002. Report of the workshop on acoustic resonance as a source of tissue trauma in cetaceans. 24-25 April, Nat. Mar. Fish. Serv., Silver Spring, MD. 19 p. Available at http://www.nmfs.noaa.gov/pr/acoustics/reports.htm

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.

Gerstein, E., L. Gerstein, S. Forsythe and J. Blue. 2004. Do manatees utilize infrasonic communication or detection? **J. Acoust. Soc. Am.** 115(5, Pt. 2):2554-2555 (Abstract).

Ghoul, A., C. Reichmuth, and J. Mulsow. 2009. Source levels and spectral analysis of southern sea otter (*Enhydra lutris nereis*) scream vocalizations. p. 90 *In*: Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Canada, Oct. 2009. 306 p.

Gisiner, R.C. (ed.). 1999. Proceedings – Workshop on the Effects of Anthropogenic Noise in the Marine Environment, Bethesda, MD, 10-12 Feb. 1998. Office of Naval Res., Arlington, VA. Available (as of Nov. 2009) at http://www.onr.navy.mil/sci_tech/34/341/docs/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 Exploration (UK) Ltd., and Aran Energy Exploration 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 R.F.W. Coates. 2006. Near source, high frequency air-gun signatures. Paper SC/58/E30 presented to the IWC Scient. Commit., IWC Annu. Meet., 1-13 June, St. Kitts.

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.

Gordon, J., R. Antunes, N. Jaquet and B. Würsig. 2006. An investigation of sperm whale headings and surface behaviour before, during and after seismic line changes in the Gulf of Mexico. Intern. Whal. Comm. Working Pap. SC/58/E45. 10 p.

Gosselin, J.-F. and J. Lawson. 2004. Distribution and abundance indices of marine mammals in the Gully and two adjacent canyons of the Scotian Shelf before and during nearby hydrocarbon seismic exploration programmes in April and July 2003. Res. Doc. 2004/133. Can. Sci. Advis. Secretariat, Fisheries & Oceans Canada. 24 p. Available at http://www.dfo-mpo.gc.ca/csas/Csas/DocREC/2004/RES2004_133_e.pdf

Greene, C.R., Jr. 1997. Physical acoustics measurements. p. 3-1 to 3-63 *In:* W.J. Richardson (ed.), Northstar marine mammal monitoring program, 1996: marine mammal and acoustical monitoring of a seismic program in the Alaskan Beaufort Sea. LGL Rep. 2121-2. Rep. from LGL Ltd., King City, Ont., and Greeneridge Sciences Inc., Santa Barbara, CA, for BP Explor. (Alaska) Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 245 p.

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, Jan. 1985, Halifax, NS. Tech. Rep. 5. Can. Oil & Gas Lands Admin., Environ. Prot. Branch, Ottawa, Ont.

Greene, C.R., Jr., N.S. Altman, and W.J. Richardson. 1999a. 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 Nat. Mar. Fish. Serv., Anchorage, AK, and Silver Spring, MD. 390 p.

Greene, C.R., Jr., N.S. Altman and W.J. Richardson. 1999b. The influence of seismic survey sounds on bowhead whale calling rates. **J. Acoust. Soc. Am.** 106(4, Pt. 2):2280 (Abstract).

Guerra, M., A.M. Thode, S.B. Blackwell, C.R. Greene Jr. and M. Macrander. 2009. Quantifying masking effects of seismic survey reverberation off the Alaskan North Slope. **J. Acoust. Soc. Am.** 126(4, Pt. 2):2230 (Abstract).

Gunn, L.M. 1988. A behavioral audiogram of the North American river otter (*Lutra canadensis*). M.S. thesis, San Diego State Univ., San Diego, CA. 40 p.

Haley, B., and W.R. Koski. 2004. Marine mammal monitoring during Lamont-Doherty Earth Observatory’s seismic program in the Northwest Atlantic Ocean, July–August 2004. LGL Rep. TA2822-27. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory, Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. November. 80 p.

Hanser, S.F., L.R. Doyle, A.R. Szabo, F.A. Sharpe and B. McCowan. 2009. Bubble-net feeding humpback whales in Southeast Alaska change their vocalization patterns in the presence of moderate vessel noise. p. 105 *In*: Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Canada, Oct. 2009. 306 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.** 17:795-812.

Harris, R.E., [R.E.] T. Elliott, and R.A. Davis. 2007. Results of mitigation and monitoring program, Beaufort Span 2-D marine seismic program, open-water season 2006. LGL Rep. TA4319-1. Rep. from LGL Ltd., King City, Ont., for GX Technol. Corp., Houston, TX. 48 p.

Hauser, D.D.W., M Holst, and V.D. Moulton. 2008. Marine mammal and sea turtle monitoring during Lamont-Doherty Earth Observatory's marine seismic program in the Eastern Tropical Pacific, April–August 2008. LGL Rep. TA4656/7-1. Rep. from LGL Ltd., King City., Ont., and St. John's, Nfld, for Lamont-Doherty Earth Observatory of Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 98 p.

HESS Team. 1999. High Energy Seismic Survey review process and interim operational guidelines for marine surveys offshore Southern California. Rep. from High Energy Seismic Survey Team for Calif. State Lands Commis. and Minerals Manage. Serv., Camarillo, CA. 39 p. + Appendices.

Available at www.mms.gov/omm/pacific/lease/fullhessrept.pdf

Hildebrand, J.A. 2005. Impacts of anthropogenic sound. p. 101-124 *In:* J.E. Reynolds, W.F. Perrin, R.R. Reeves, S. Montgomery, and T. Ragen (eds.), Marine Mammal Research: Conservation Beyond Crisis. Johns Hopkins Univ. Press, Baltimore, MD. 223 p.

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

Holst, M. and M.A. Smultea. 2008. Marine mammal and sea turtle monitoring during Lamont-Doherty Earth Observatory's marine seismic program off Central America, February – April 2008. LGL Rep. TA4342-3. 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. 133 p.

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.

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.

Holst, M., W.J. Richardson, W.R. Koski, M.A. Smultea, B. Haley, M.W. Fitzgerald, and M. Rawson. 2006. Effects of large- and small-source seismic surveys on marine mammals and sea turtles. **Eos**, Trans. Am. Geophys. Union 87(36), Joint Assembly Suppl., Abstract OS42A-01. 23-26 May, Baltimore, MD.

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

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

IAGC. 2004. Further analysis of 2002 Abrolhos Bank, Brazil humpback whale strandings coincident with seismic surveys. Intern. Assoc. Geophys. Contractors, Houston, TX. 12 p.

Ireland, D., M. Holst, and W.R. Koski. 2005. Marine mammal monitoring during Lamont-Doherty Earth Observatory's seismic program off the Aleutian Islands, Alaska, July-August 2005. LGL Rep. TA4089-3. 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. 67 p.

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

Jefferson, T.A. and B.E. Curry. 1994. Review and evaluation of potential acoustic methods of reducing or eliminating marine mammal-fishery interactions. Rep. from the Mar. Mamm. Res. Progr., Texas A & M Univ., College Station, TX, for U.S. Mar. Mamm. Commis., 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.

Jochens, A., D. Biggs, K. Benoit-Bird, D. Engelhaupt, J. Gordon, C. Hu, N. Jaquet, M. Johnson, R. Leben, B. Mate, P. Miller, J. Ortega-Ortiz, A. Thode, P. Tyack, and B. Würsig. 2008. Sperm whale seismic study in the Gulf of Mexico/Synthesis report. OCS Study MMS 2008-006. Rep. from Dep. Oceanogr., Texas A & M Univ., College Station, TX, for U.S. Minerals Manage. Serv., Gulf of Mexico OCS Reg., New Orleans, LA. 323 p.

Johnson, M.P. and P.L. Tyack. 2003. A digital acoustic recording tag for measuring the response of wild marine mammals to sound. **IEEE J. Oceanic Eng.** 28(1):3-12.

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

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(2):1142-1148.

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.

Kastelein, R.A., W.C. Verboom, N. Jennings, and D. de Haan. 2008. Behavioral avoidance threshold level of a harbor porpoise (*Phocoena phocoena*) for a continuous 50 kHz pure tone (L). **J. Acoust. Soc. Am.** 123(4): 1858-1861.

Kastelein, R.A., P.J. Wensveen, L. Hoek, W.C. Verboom and J.M. Terhune. 2009. Underwater detection of tonal signals between 0.125 and 100 kHz by harbor seals (*Phoca vitulina*). **J. Acoust. Soc. Am.** 125(2):1222-1229.

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, NY.

Ketten, D.R. 1994. Functional analysis of whale ears: adaptations for underwater hearing. **IEEE Proc. Underwater 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 Publishers, Woerden, Netherlands. 588 p.

Ketten, D.R. 1998. Marine mammal auditory systems: a summary of audiometric and anatomical data and its implications for underwater acoustic impacts. NOAA Tech. Memo. NOAA-TM-NMFS-SWFSC-256. Southwest Fisheries Sci. Cent., La Jolla, CA. 74 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 (Abstract).

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 (Abstract).

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.

Koski, W.R., D.W. Funk, D.S. Ireland, C. Lyons, K. Christie, A.M. Macrander and S.B. Blackwell. 2009. An update on feeding by bowhead whales near an offshore seismic survey in the central Beaufort Sea. Intern. Whal. Comm. Working Pap. SC/61/BRG3. 15 p

Kraus, S., A. Read, A. Solov, K. Baldwin, T. Spradlin, E. Anderson, and J. Williamson. 1997. Acoustic alarms reduce porpoise mortality. **Nature** 388(6642):525.

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. **Antarctic Sci.** 17(1):3-10.

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.

Laurinolli, M.H. and N.A. Cochrane. 2005. Hydroacoustic analysis of marine mammal vocalization data from ocean bottom seismometer mounted hydrophones in the Gully. p. 89-95 *In:* K. Lee, H. Bain and G.V. Hurley (eds.), Acoustic monitoring and marine mammal surveys in The Gully and Outer Scotian Shelf before and during active seismic surveys. Environ. Stud. Res. Funds Rep. 151. 154 p. Published 2007.

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.

Lucke, K., U. Siebert, P.A. Lepper and M.-A. Blanchet. 2009. Temporary shift in masked hearing thresholds in a harbor porpoise (*Phocoena phocoena*) after exposure to seismic airgun stimuli. **J. Acoust. Soc. Am.** 125(6):4060-4070.

Lusseau, D. and L. Bejder. 2007. The long-term consequences of short-term responses to disturbance experience from whalewatching impact assessment. **Intern. J. Compar. Psychol.** 20(2-3):228-236.

MacGillivray, A.O. and D. Hannay. 2007a. Summary of noise assessment. p. 3-1 to 3-21 *In:* Marine mammal monitoring and mitigation during open water seismic exploration by ConocoPhillips Alaska, Inc., in the Chukchi Sea, July-October 2006. LGL Rep. P903-2 (Jan. 2007). Rep. from LGL Alaska Res. Assoc. Inc., Anchorage, AK, and JASCO Res. Ltd., Victoria, B.C., for ConocoPhillips Alaska Inc., Anchorage, AK, and Nat. Mar. Fish. Serv., Silver Spring, MD. 116 p.

MacGillivray, A. and D. Hannay. 2007b. Field measurements of airgun array sound levels. p. 4-1 to 4-19 *In:* Marine mammal monitoring and mitigation during open water seismic exploration by GX Technology in the Chukchi Sea, October-November 2006: 90-day report. LGL Rep. P891-1 (Feb. 2007). Rep. from LGL

Alaska Res. Assoc. Inc., Anchorage, AK, and JASCO Res. Ltd., Victoria, B.C., for GX Technology, Houston, TX, and Nat. Mar. Fish. Serv., Silver Spring, MD. 118 p.

MacLean, S.A. and B. Haley. 2004. Marine mammal monitoring during Lamont-Doherty Earth Observatory's seismic study in the Støregga Slide area of the Norwegian Sea, August - September 2003. LGL Rep. TA2822-20. Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory, Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 59 p.

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, Ont., for Lamont-Doherty Earth Observatory, Columbia Univ., Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD. 102 p.

Madsen, P.T. 2005. Marine mammals and noise: problems with root mean square sound pressure levels for transients. **J. Acoust. Soc. Am.** 117(6):3952-3957.

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.

Madsen, P.T., M. Johnson, P.J.O. Miller, N. Aguilar de Soto, J. Lynch, and P.L. Tyack. 2006. Quantitative measures of air gun pulses recorded on sperm whales (*Physeter macrocephalus*) using acoustic tags during controlled exposure experiments. **J. Acoust. Soc. Am.** 120(4):2366–2379.

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, NS. Tech. Rep. 5. Can. Oil & Gas Lands Admin., Environ. Prot. Br., Ottawa, Ont. 398 p.

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

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

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. BBN Rep. 6265. OCS Study MMS 88-0048. Outer Contin. Shelf Environ. Assess. Progr., Final Rep. Princ. Invest., NOAA, Anchorage 56(1988): 393-600. NTIS PB88-249008.

Malme, C.I., B. Würsig, B., 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. Symposium on Noise and Marine Mammals. Univ. Alaska Fairbanks, Fairbanks, AK. 111 p.

Manly, B.F.J., V.D. Moulton, R.E. Elliott, G.W. Miller and W.J. Richardson. 2007. Analysis of covariance of fall migrations of bowhead whales in relation to human activities and environmental factors, Alaskan Beaufort Sea: Phase I, 1996-1998. LGL Rep. TA2799-2; OCS Study MMS 2005-033. Rep. from LGL Ltd., King City, Ont., and WEST Inc., Cheyenne, WY, for U.S. Minerals Manage. Serv., Herndon, VA, and Anchorage, AK. 128 p.

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. Prog., 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(5, Pt. 2):3268-3269 (Abstract).

McAlpine, D.F. 2002. Pygmy and dwarf sperm whales. p. 1007-1009 *In:* W.F. Perrin, B. Würsig, and J.G.M. Thewissen (eds.), Encyclopedia of Marine Mammals. Academic Press, San Diego, CA. 1414 p.

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

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, Western Australia, for Australian Petrol. Produc. & Explor. Association, Sydney, NSW. 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.

McShane, L.J., J.A. Estes, M.L. Riedman, and M.M. Staedler. 1995. Repertoire, structure, and individual variation of vocalizations in the sea otter. **J. Mammal.** 76(2):414-427.

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

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

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

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

Mooney, T.A., P.E. Nachtigall, M. Breese, S. Vlachos, and W.W.L. Au, 2009a. Predicting temporary threshold shifts in a bottlenose dolphin (*Tursiops truncatus*): the effects of noise level and duration. **J. Acoust. Soc. Am.** 125(3):1816-1826.

Mooney, T.A., P.E. Nachtigall and S. Vlachos. 2009b. Sonar-induced temporary hearing loss in dolphins. **Biol. Lett.** 4(4):565-567.

Moore, S.E. and Angliss, R.P. 2006. Overview of planned seismic surveys offshore northern Alaska, July-October 2006. Paper SC/58/E6 presented to IWC Scient. Commit., IWC Annu. Meet., 1-13 June, St Kitts.

Morton A.B. and H.K. Symonds. 2002. Displacement of *Orcinus orca* (L.) by high amplitude sound in British Columbia, Canada. **ICES J. Mar. Sci.** 59(1):71-80

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. LGL Rep. TA2564-4. 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. 95 p.

Moulton, V.D. and G.W. Miller. 2005. Marine mammal monitoring of a seismic survey on the Scotian Slope, 2003. p. 29-40 *In:* K. Lee, H. Bain, and G.V. Hurley (eds.), Acoustic monitoring and marine mammal surveys in the Gully and outer Scotian Shelf before and during active seismic programs. Environ. Stud. Res. Funds Rep. 151. 154 p (Published 2007).

Moulton, V.D., B.D. Mactavish, and R.A. Buchanan. 2005. Marine mammal and seabird monitoring of Chevron Canada Resources' 3-D seismic program on the Orphan Basin, 2004. LGL Rep. SA817. Rep. by LGL Ltd., St. John's, NL, for Chevron Canada Resources, Calgary, Alb., ExxonMobil Canada Ltd., St. John's, Nfld., and Imperial Oil Resources Ventures Ltd., Calgary, Alb. 90 p. + appendices.

Moulton, V.D., B.D. Mactavish, R.E. Harris, and R.A. Buchanan. 2006a. Marine mammal and seabird monitoring of Chevron Canada Limited's 3-D seismic program on the Orphan Basin, 2005. LGL Rep. SA843. Rep. by LGL Ltd., St. John's, Nfld., for Chevron Canada Resources, Calgary, Alb., ExxonMobil Canada Ltd., St. John's, Nfld., and Imperial Oil Resources Ventures Ltd., Calgary, Alb. 111 p. + appendices.

Moulton, V.D., B.D. Mactavish, and R.A. Buchanan. 2006b. Marine mammal and seabird monitoring of Conoco-Phillips' 3-D seismic program in the Laurentian Sub-basin, 2005. LGL Rep. SA849. Rep. by LGL Ltd., St. John's, Nfld., for ConocoPhillips Canada Resources Corp., Calgary, Alb. 97 p. + appendices.

Nachtigall, P.E., J.L. Pawloski, and W.W.L. Au. 2003. Temporary threshold shifts and recovery following noise exposure in the Atlantic bottlenose 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

Nachtigall, P.E., A.Y. Supin, M. Amundin, B. Röken,,T. Møller, A. Mooney, K.A. Taylor, and M. Yuen. 2007. Polar bear *Ursus maritimus* hearing measured with auditory evoked potentials. **J. Exp. Biol.** 210(7):1116-1122.

Nations, C.S., S.B. Blackwell, K.H. Kim, A.M. Thode, C.R. Greene Jr., A.M. Macrander, and T.L. McDonald. 2009. Effects of seismic exploration in the Beaufort Sea on bowhead whale call distributions. **J. Acoust. Soc. Am.** 126(4, Pt. 2):2230 (Abstract).

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. p. 205 *In*: Abstr. 16th Bienn. Conf. Biol. Mar. Mamm., San Diego, CA, 12-16 Dec. 2005.

Nieukirk, S.L., S.L. Heimlich, S.E. Moore, K.M. Stafford, R.P. Dziak, M. Fowler, J. Haxel, J. Goslin and D.K. Mellinger. 2009. Whales and airguns: an eight-year acoustic study in the central North Atlantic. p. 181-182 *In*: Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Oct. 2009. 306 p.

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

NMFS. 2000. Small takes of marine mammals incidental to specified activities; marine seismic-reflection data collection in southern California. **Fed. Regist.** 65(20):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):9291-9298.

NMFS. 2005. Endangered Fish and Wildlife; Notice of Intent to Prepare an Environmental Impact Statement. **Fed. Regist.** 70(7):1871-1875.

NOAA and U.S. Navy. 2001. Joint interim report: Bahamas marine mammal stranding event of 15-16 March 2000. Nat. Mar. Fish. Serv., Silver Spring, MD, and Assistant Secretary of the Navy, Installations & Environ., Washington, DC. 61 p. Available at http://www.nmfs.noaa.gov/pr/acoustics/reports.htm

Nowacek, D.P., L.H. Thorne, D.W. Johnston, and P.L. Tyack. 2007. Responses of cetaceans to anthropogenic noise. **Mammal Rev.** 37(2):81-115.

NRC. 2005. Marine Mammal Populations and Ocean Noise: Determining When Noise Causes Biologically Significant Effects. U. S. Nat. Res. Counc., Ocean Studies Board. (Authors D.W. Wartzok, J. Altmann, W. Au, K. Ralls, A. Starfield, and P.L. Tyack). Nat. Acad. Press, Washington, DC. 126 p.

Parente, C.L., M.C.C. Marcondes, and M.H. Engel. 2006. Humpback whale strandings and seismic surveys in Brazil from 1999 to 2004. Intern. Whal. Commis. Working Pap. SC/58/E41. 16 p.

Parente, C.L., J.P. de Araújo and M.E. de Araújo. 2007. Diversity of cetaceans as tool in monitoring environmental impacts of seismic surveys. **Biota Neotrop.** 7(1):1-7.

Parks, S.E., C.W. Clark, and P.L. Tyack. 2007a. Short- and long-term changes in right whale calling behavior: the potential effects of noise on acoustic communication. **J. Acoust. Soc. Am.** 122(6):3725-3731.

Parks, S.E., D.R. Ketten, J.T. O'Malley and J. Arruda. 2007b. Anatomical predictions of hearing in the North Atlantic right whale. **Anat. Rec.** 290(6):734-744.

Parks, S.E., I. Urazghildiiev and C.W. Clark. 2009. Variability in ambient noise levels and call parameters of North Atlantic right whales in three habitat areas. **J. Acoust. Soc. Am.** 125(2):1230-1239.

Potter, J.R., M. Thillet, C. Douglas, M.A. Chitre, Z. Doborzynski, and P.J. Seekings. 2007. Visual and passive acoustic marine mammal observations and high-frequency seismic source characteristics recorded during a seismic survey. **IEEE J. Oceanic Eng.** 32(2):469-483.

Reeves, R.R. 1992. Whale responses to anthropogenic sounds: A literature review. Sci. & Res. Ser. 47. New Zealand Dep. Conserv., Wellington. 47 p.

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. Nat. Mar. Fish. Serv., Northwest Fisheries Sci. Cent., Seattle, WA. 70 p.

Reiser, C.M., B. Haley, J. Beland, D.M. Savarese, D.S. Ireland, and D.W. Funk. 2009. Evidence of short-range movements by phocid species in reaction to marine seismic surveys in the Alaskan Chukchi and Beaufort seas. p. 211 *In*:Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Canada, Oct. 2009. 306 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. Freshw. 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, CA. 576 p.

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

Richardson, W.J., M. Holst, W.R. Koski and M. Cummings. 2009. Responses of cetaceans to large-source seismic surveys by Lamont-Doherty Earth Observatory. p. 213 *In*: Abstr. 18th Bienn. Conf. Biol. Mar. Mamm., Québec, Oct. 2009. 306 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 Center for Coastal Marine Studies, Univ. Calif., Santa Cruz, CA, for MMS, 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 BBN Inc., Cambridge, MA, for Minerals Manage. Serv. Anchorage, AK. NTIS 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(7):1124-1134.

SACLANT. 1998. Estimation of cetacean hearing criteria levels. Section II, Chapter 7 *In:* SACLANTCEN Bioacoustics Panel Summary Record and Report. Rep. from NATO Undersea Res. Center. Available at http://enterprise.spawar.navy.mil/nepa/whales/pdf/doc2-7.pdf

Scheifele, P.M., S. Andrew, R.A. Cooper, M. Darre, F.E. Musiek, and L. Max. 2005. Indication of a Lombard vocal response in the St. Lawrence River beluga. **J. Acoust. Soc. Am.** 117(3, Pt. 1):1486-1492.

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.

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

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

Smultea, M.A. and M. Holst. 2008. Marine mammal monitoring during a University of Texas Institute for Geophysics seismic survey in the Northeast Pacific Ocean, July 2008. LGL Rep. TA4584-2. 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. 80 p.

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.

Sodal, A. 1999. Measured underwater acoustic wave propagation from a seismic source. Proc. Airgun Environmental Workshop, 6 July, London, UK.

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

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

Stone, C.J. and M.L. Tasker. 2006. The effects of seismic airguns on cetaceans in UK waters. **J. Cetac. Res. Manage.** 8(3):255-263.

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.

Thomas, J.A., R.A. Kastelein and F.T. Awbrey. 1990. Behavior and blood catecholamines of captive belugas during playbacks of noise from an oil drilling platform. **Zoo Biol.** 9(5):393-402.

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:* Abstr. 12th Bienn . Conf. and World Mar. Mamm. Sci. Conf., 20-25 Jan., Monte Carlo, Monaco. 160 p.

Thomson, D.H. and W.J. Richardson. 1995. Marine mammal sounds. p. 159-204 *In:* W.J. Richardson, C.R. Greene, Jr., C.I. Malme, and D.H. Thomson. Marine Mammals and Noise. Academic Press, San Diego, CA. 576 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 Rep. from LGL Ltd., King City, Ont., for Lamont-Doherty Earth Observatory, Palisades, NY, and Nat. Mar. Fish. Serv., Silver Spring, MD.

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. Let.** 31:L14310. doi: 10.1029/2004GL020234

Tolstoy, M., J. Diebold, L. Doermann, S. Nooner, S.C. Webb, D.R. Bohnenstiehl, T.J. Crone and R.C. Holmes. 2009. Broadband calibration of the R/V *Marcus G. Langseth* four-string seismic sources. **Geochem. Geophys. Geosyst.** 10(8):1-15. Q08011.

Tyack, P.L. 2008. Implications for marine mammals of large-scale changes in the marine acoustic environment. **J. Mammal.** 89(3):549-558.

Tyack, P.L. 2009. Human-generated sound and marine mammals. **Phys. Today** 62(11, Nov.):39-44.

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 Region, New Orleans, LA.

Tyack, P.L., M.P. Johnson, P.T. Madsen, P.J. Miller, and J. Lynch. 2006a. Biological significance of acoustic impacts on marine mammals: examples using an acoustic recording tag to define acoustic exposure of sperm whales, *Physeter catodon*, exposed to airgun sounds in controlled exposure experiments. **Eos**, Trans. Am. Geophys. Union 87(36), Joint Assembly Suppl., Abstract OS42A-02. 23-26 May, Baltimore, MD.

Tyack, P.L., M. Johnson, N. Aguilar Soto, A. Sturlese, and P.T. Madsen. 2006b. Extreme diving of beaked whales. **J. Exp. Biol.** 209(21):4238-4253.

Urick, R.J. 1983. Principles of Underwater Sound. 3rd ed. Peninsula Publ., Los Altos, CA. 423 p.

van der Woude, S. 2007. Assessing effects of an acoustic marine geophysical survey on the behaviour of bottlenose dolphins *Tursiops truncatis*. *In:* Abstr. 17th Bienn. Conf. Biol. Mar. Mamm., 29 Nov.–3 Dec., Cape Town, South Africa.

Wartzok, D., A.N. Popper, J. Gordon, and J. Merrill. 2004. Factors affecting the responses of marine mammals to acoustic disturbance. **Mar. Technol. Soc. J.** 37(4):6-15.

Watkins, W.A. 1977. Acoustic behavior of sperm whales. **Oceanus** 20(2):50-58.

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.

Weilgart, L.S. 2007. A brief review of known effects of noise on marine mammals. **Intern. J. Comp. Psychol.** 20:159-168.

Weir, C.R. 2008a. Overt responses of humpback whales (*Megaptera novaeangliae*), sperm whales (*Physeter macrocephalus*), and Atlantic spotted dolphins (*Stenella frontalis*) to seismic exploration off Angola. **Aquat. Mamm.** 34(1):71-83.

Weir, C.R. 2008b. Short-finned pilot whales (*Globicephala macrorhynchus*) respond to an airgun ramp-up procedure off Gabon. **Aquat. Mamm.** 34(3):349-354.

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

Weller, D.W., S.H. Rickards, A.L. Bradford, A.M. Burdin, and R.L. Brownell, Jr. 2006a. The influence of 1997 seismic surveys on the behavior of western gray whales off Sakhalin Island, Russia. Paper SC/58/E4 presented to the IWC Scient. Commit., IWC Annu. Meet., 1-13 June, St. Kitts.

Weller, D.W., G.A. Tsidulko, Y.V. Ivashchenko, A.M. Burdin and R.L. Brownell Jr. 2006b. A re-evaluation of the influence of 2001 seismic surveys on western gray whales off Sakhalin Island, Russia. Paper SC/58/E5 presented to the IWC Scient. Commit., IWC Annu. Meet., 1-13 June, St. Kitts.

Wieting, D. 2004. Background on development and intended use of criteria. p. 20 *In:* S. Orenstein, L. Langstaff, L. Manning, and R. Maund (eds.), Advisory Committee on Acoustic Impacts on Marine Mammals, Final Meet. Summary. Second Meet., April 28-30, 2004, Arlington, VA. Sponsored by the Mar. Mamm. Commis., 10 Aug.

Winsor, M.H. and B.R. Mate. 2006. Seismic survey activity and the proximity of satellite tagged sperm whales. Intern. Whal. Comm. Working Pap. SC/58/E16. 8 p.

Wright, A.J. and S. Kuczaj. 2007. Noise-related stress and marine mammals: An Introduction. **Intern. J. Comp. Psychol.** 20(2-3):iii-viii.

Wright, A.J., N. Aguilar Soto, A.L. Baldwin, M. Bateson, C.M. Beale, C. Clark, T. Deak, E.F. Edwards, A. Fernández, A. Godinho, L.T. Hatch, A. Kakuschke, D. Lusseau, D. Martineau, L.M. Romero, L.S. Weilgart, B.A. Wintle, G. Notarbartolo-di-Sciara, and V. Martin. 2007a. Do marine mammals experience stress related to anthropogenic noise? **Intern. J. Comp. Psychol.** 20(2-3):274-316.

Wright, A.J., N. Aguilar Soto, A.L. Baldwin, M. Bateson, C.M. Beale, C. Clark, T. Deak, E.F. Edwards, A. Fernández, A. Godinho, L.T. Hatch, A. Kakuschke, D. Lusseau, D. Martineau, L.M. Romero, L.S. Weilgart, B.A. Wintle, G. Notarbartolo-di-Sciara and V. Martin. 2007b. Anthropogenic noise as a stressor in animals: A multidisciplinary perspective. **Intern. J. Comp. Psychol.** 20(2-3): 250-273.

Wright, A.J., T. Deak and E.C.M. Parsons. 2009. Concerns related to chronic stress in marine mammals. Intern. Whal. Comm. Working Pap. SC/61/E16. 7 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. Rep. from Texas A&M Univ., College Station, TX, and Kamchatka Inst. Ecol. & Nature Manage., Russian Acad. Sci., Kamchatka, Russia, for Sakhalin Energy Investment Co. Ltd and Exxon Neftegaz Ltd, Yuzhno-Sakhalinsk, Russia. 101 p.

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

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

Yoder, J.A. 2002. Declaration 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 Calif., San Francisco Div.