United States Department of the Interior

U. S. GEOLOGICAL SURVEY
Pacific Coastal and Marine Science Center
Mail Stop 999
345 Middlefield Rd.
Menlo Park California 94025

May 27, 2010

National Marine Fisheries Service
Office of Protected Resources
Marine Mammal Division
Attn: James H. Lecky, Director
1315 East–West Highway
Silver Spring, MD 290910-3226

Dear Mr. Lecky,

Attached please find an application for an Incidental Harassment Authorization (IHA) titled "Request by U.S. Geological Survey (USGS) for an Incidental Harassment Authorization to Allow the Incidental Take of Marine Mammals During a Marine Seismic Survey of the Arctic Ocean, August–September 2010." The application has been prepared pursuant to Section 101(a)(5)(D) of the Marine Mammal Protection Act, 16 U.S.C. § 1371. The USGS received technical assistance from LGL Alaska Research Associates, Inc. in the preparation of the application.

The U.S. Coast Guard (USCG) is a cooperating agency for the USGS's review of the proposed project under the National Environmental Policy Act (NEPA). They have expressed strong reservations about the requirement that icebreaking *per se* be addressed in the environmental assessment (EA) and IHA application.. The Coast Guard's reservations are presented below:

> "It is important to note that non-icebreaking vessels – as well as natural sounds such as those arising from sea ice motion and whale flukes hitting the ocean surface - also present similar sound impacts. Underwater noise from various vessels – including tug boats, oceanographic research vessels, and fisheries research vessels in open water, as well as icebreakers traversing sea ice - often exceed 120 dB, the existing threshold for Level B harassment set by NMFS (2005).
>
> Given the lack of measurements, the absence of peer review and other necessary protocols, it would be unfair and unfounded to reach conclusions as to harassment of animals by sound based upon limited studies alone. Before any of these sounds are determined to be a source of harassment of one or more animal populations under law, the range of sound should be compared, and combined if necessary. It would be inappropriate to single out one or the other for unduly burdensome requirements. It should also be noted that no regulatory provisions have been adopted for vessel sound as a source of harassment.
>
> However, due to a verbal request from National Marine Fisheries Service, [takes have been calculated] as if the level for icebreaking were established. These calculations are for information purposes only and do not represent any conclusions with regard to harassment. Further studies are needed before such a precedent can be established."

Hardcopy of this application will be provided by overnight for delivery no later than June 1, 2010. The hardcopy package will include the most recent versions of the application in PDF and Microsoft Word format. Please feel free to contact me if you have any questions concerning our application.

Sincerely,

Jonathan R. Childs
Geophysicist
(650) 329-5195
jchilds@usgs.gov

cc: USGS Environmental Management Branch, Reston, VA

Request by the U.S. Geological Survey for an Incidental Harassment Authorization to Allow the Incidental Take of Marine Mammals during a Marine Seismic Survey of the Arctic Ocean, August–September 2010

submitted by

U.S. Geological Survey
345 Middlefield Rd.
Menlo Park, CA 94025

to

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

Application prepared by

Alaska Research Associates, Inc.

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

May 2010

LGL Document P1122-2

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Request by the U.S. Geological Survey for an Incidental Harassment Authorization to Allow the Incidental Take of Marine Mammals during a Marine Seismic Survey of the Arctic Ocean, August–September 2010

SUMMARY

Several species of cetaceans and pinnipeds that inhabit the Beaufort Sea and Arctic Ocean may be encountered during the proposed geophysical survey. Few species that may be found in the study area are listed as “Endangered” under the U.S. Endangered Species Act (ESA). The bowhead whale is the one endangered species that is most likely to occur within the survey area. Survey activities will be located in deep water well north of the normal bowhead migration corridor and subsistence hunting areas. The U.S. Geological Survey (USGS) is adopting a marine mammal monitoring and mitigation program to minimize the impacts of the proposed activity on marine mammals during the exploration activity, and to document the nature and extent of any effects.

The items required to be addressed pursuant to 50 C.F.R. § 216.104, “Submission of Requests” are set forth below. This includes descriptions of: the specific operations to be conducted and where they will occur, the marine mammal species and critical habitat occurring in the proposed survey, proposed measures to mitigate any potential injurious effects on marine mammals, and a plan to monitor behavioral effects of the operations on marine mammals.

I. OPERATIONS TO BE CONDUCTED

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

Overview of the Activity

The specific activities to be addressed consist of geophysical (seismic reflection/refraction) and bathymetric surveys in the Arctic Ocean to be conducted in August and September 2010 (Tables 1 and 2, Fig. 1). The survey will be conducted from the Canadian Coast Guard (CCG) vessel CCGS *Louis S. St. Laurent* which will be accompanied by the U.S. Coast Guard Cutter (USCGC) *Healy,* both of which are polar–class icebreakers. Descriptions of the vessels and their specifications are presented in Appendix A. The two vessels will operate in tandem in the presence of ice but may diverge and operate independently in open water.

One CCG helicopter will be available for deployment from the *Louis S. St. Laurent* for ice reconnaissance and crew transfers between the vessels during survey operations. Helicopter transfer of crew from *Healy* is also planned for ~1 day during a ship-to-shore crew change at Barrow at the end of the survey. The helicopter operations in Barrow will be conducted under Department of Interior (DOI) contract. Daily helicopter operations are anticipated pending weather conditions. Spot bathymetry will also be conducted from the helicopter outside U.S. waters.

Acoustic sources on board the *Louis S. St. Laurent* will include an airgun array comprised of three Sercel G-guns and a Knudsen 320BR “Chirp” pulse echo sounder operating at 12 kHz. The *Louis S. St. Laurent* will also tow a 3–5 kHz sub-bottom profiler while in open water and when not working with the

Healy. The airgun array consists of two 500 in^3 and one 150 in^3 airguns for an overall discharge of 1150 in^3. Table 2 presents proposed sound pressure level radii of the airgun array. Acoustic sources that will be operated on the *Louis S. St. Laurent* are described in detail in Section VII and Appendix B. The seismic array and a hydrophone streamer towed from the *Louis S. St. Laurent* will operate under the provisions of a Canadian authorization based on Canada's environmental assessment of the proposed survey while in Canadian or international waters, and under the provisions of an IHA issued by NMFS in U.S. waters. The *Healy* will break and clear ice ~1 to 2 miles in advance of the *Louis S. St. Laurent*. In situations where the array (and hydrophone streamer) cannot be towed safely due to ice cover, the *Louis S. St. Laurent* may escort the *Healy*. The *Healy* will use a multibeam echo sounder, (Kongsberg EM122), a sub-bottom profiler (Knudsen 3.5 kHz Chirp) and a "piloting" echo sounder (ODEC 1500) continuously when underway and during the seismic profiling. Acoustic Doppler current profilers (75-kHz and 150-kHz) may also be used on the *Healy*. The *Healy's* acoustic systems are described in further detail in Section VII and Appendix B.

In addition to the hydrophone streamer, marine sonobuoys will be deployed to acquire wide angle reflection and refraction data for velocity determination to convert seismic reflection travel time to depth. Sonobuoys will be deployed off the stern of the *Louis S. St. Laurent* approximately every eight hours during seismic operations with as many as three deployments per day. The sonobuoy's hydrophone will activate at a water depth of ~60 m and seismic signals will be communicated via radio to the *Louis S. St. Laurent*. The sonobuoys are pre-set to scuttle eight hours after activation.

The program within U.S. waters will consist of ~806 km of survey transect line, not including transits when the airguns are not operating (Fig. 1; Table 1). U.S. priorities include another 997 km of survey lines north of the U.S. EEZ, for a total of 1804 km of tracklines of interest to the U.S. Table 1 lists all U.S. priority tracklines; Fig. 1 includes all U.S. priority tracks and the area of interest to Canada near the proposed U.S. tracklines. Water depths within the U.S. study area will range from ~1900 to 4000 m (Fig. 1). There may be additional seismic operations associated with airgun testing, start up, and repeat coverage of any areas where initial data quality is sub-standard. The tracklines that will be surveyed in U.S. waters include the southern 263.8 km of the line that runs North-South in the western EEZ, the southern 264.5 km of the line that runs North-South in the central EEZ, and 277.7 km trackline of the line that connects the two (Fig. 1; Table 1). This Incidental Harassment Authorization application requests the permitting of incidental takes of marine mammals for the activities within U.S. waters.

TABLE 1. Proposed U.S. priority tracklines for USGS/Geological Survey of Canada (GSC) 2010 Extended Continental Shelf Survey in the northern Beaufort Sea and Arctic Ocean.

Location	End Point 1	End Point 2	km	n.mi.	Time (h) @ 4 n.mi./hr
NS in central EEZ (south)	71.22° N ; 145.17° W	72.27° N ; 145.41° W	118	64	16
NS in central EEZ (north)	72.27° N ; 145.41° W	73.92° N ; 145.30° W	183	100	25
Central-western EEZ connector	73.92° N ; 145.30° W	71.84° N ; 151.82° W	317	171	43
NS in western EEZ	71.84° N ; 151.82° W	74.32° N ; 150.30°W	281	152	39
South Northwind Ridge	74.32° N ; 150.30°W	74.96° N ; 158.01° W	239	129	32
Northwind Ridge connector	74.96° N ; 158.01° W	76.30° N ; 155.88° W	161	87	22
Mid-Northwind Ridge	76.30° N ; 155.88° W	75.41° N ; 146.50° W	274	148	37
Northwind Ridge connector	75.41° N ; 146.50° W	76.57° N ; 146.82° W	129	70	17
Mid-Northwind Ridge	76.57° N ; 146.82° W	76.49° N ; 150.73° W	102	55	14
		Totals	1804	976	245

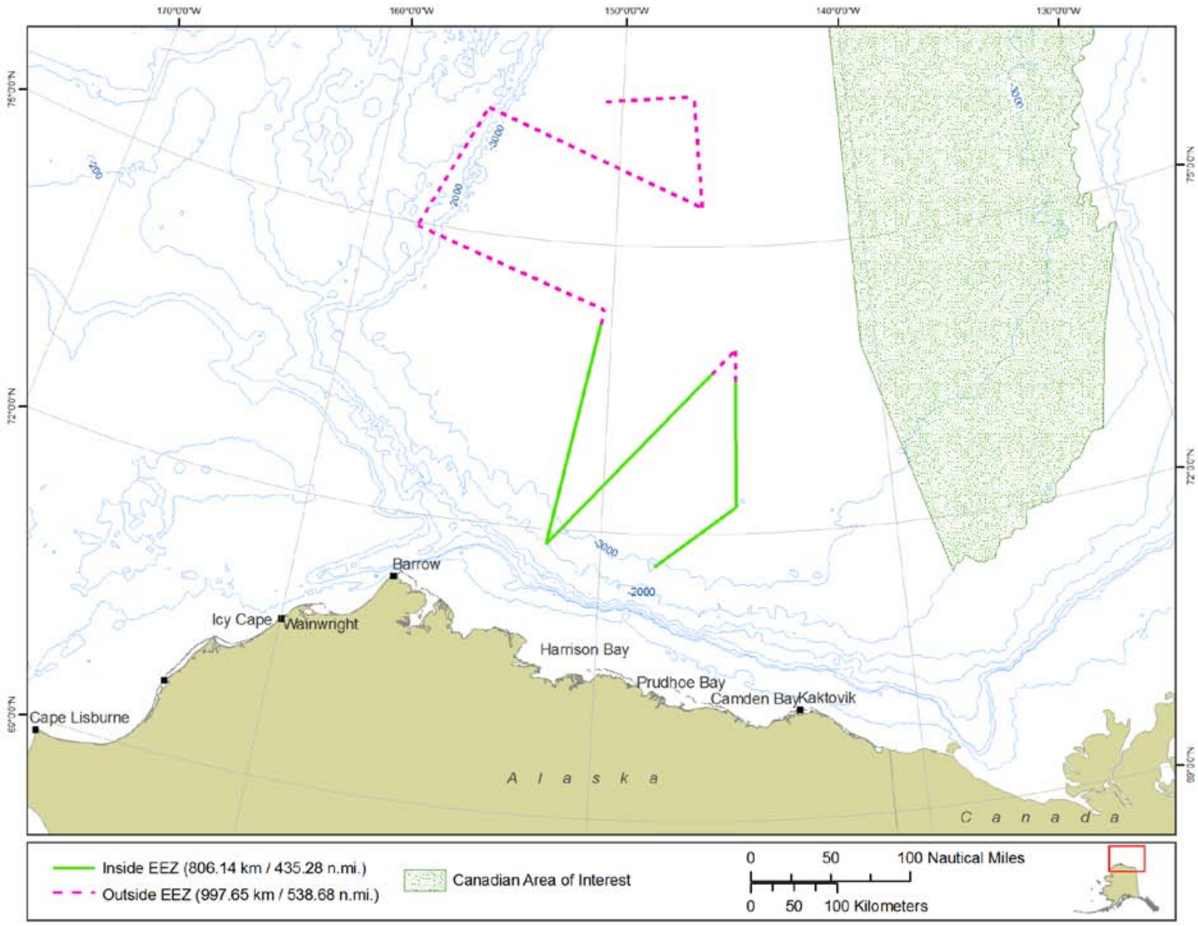

FIGURE 1. Proposed location of the USGS August–September 2010 seismic survey area.

TABLE 2. Proposed sound-level radii for the three-airgun array and mitigation airgun for the USGS seismic survey.

	Estimated Distances for Received Levels (m)		
Seismic Source Volume	190 dB rns	180 dB rms	160 dB rms
150 in^3 mitigation gun	30	75	750
1150 in^3 (three G-gun array)	100	500	2500

Description of Operations

Two vessels will operate cooperatively during the proposed geophysical survey. The *Louis S. St. Laurent* will conduct seismic operations using an airgun array and also operate a 12 kHz Chirp echo sounder. The *Louis S. St. Laurent* will also operate a 3–5 kHz sub-bottom profiler in open water when not working with the *Healy*. The *Healy* will normally escort the *Louis S. St. Laurent* in ice cover, and will continuously operate a bathymetric multibeam echo sounder, a 3.5 kHz Chirp sub-bottom profiler, a piloting echo sounder, and two acoustic Doppler current profilers.

The *Louis S. St. Laurent* will access the survey area from Canada and rendezvous with the *Healy* on approximately 7 August, the *Healy* will approach the survey area from the Bering Straits. The *Louis S. St. Laurent* will deploy a relatively small airgun array comprised of three G-guns and a single hydrophone streamer ~300 m in length. The airgun array consists of two 500 in^3 and one 150 in^3 airguns for an overall discharge of 1150 in^3. The *Louis S. St. Laurent* will follow the lead of the *Healy* which will operate ~1 to 2 n.mi. ahead of the *Louis S. St. Laurent*. In ice conditions where seismic gear cannot be safely towed, the *Louis S. St. Laurent* will escort *Healy* to optimize multibeam bathymetry data collection. If extended open-water conditions are encountered, *Healy* and *Louis S. St. Laurent* may operate independently.

The U.S. priority survey lines will consist of eight transect lines ranging in length from ~102 to 317 km, totalling ~1804 km of trackline (Table 1; Fig. 1). These tracklines are planned in water depths of 1900 to 4000 m. Approximately 806 km of trackline will be surveyed within U.S. waters. The survey line nearest to shore in U.S. waters is ~108 km (63 n.mi.) offshore at its closest point. After completion of the survey the *Louis S. St. Laurent* will return to port in Canada, and the *Healy* will change crew at Barrow via helicopter or surface conveyance before continuing on another project.

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 ~30 days from approximately 7 August to 3 September 2010. The ~806 km of tracklines within U.S. waters will be surveyed first. These survey lines are expected to be completed by approximately 12 August. The seismic vessel *Louis S. St. Laurent* will depart from Kugluktuk, Nunavut, Canada on 2 August and return to the same port approximately 16 September. The *Healy* will depart from Dutch Harbor on ~3 August to meet the *Louis S. St. Laurent* by 7 August. After completion of this survey, the *Healy* will change crew through Barrow via helicopter or surface vessel on 4 September (Table 3).

The entire survey area will be bounded approximately by 145º to 158º W longitude and 71º to 84º N latitude in water depths ranging from ~1900–4000 m (Fig. 1; Table 1). Ice conditions are expected to range from open water to 10/10 ice cover.

TABLE 3. Synopsis of 2010 *Louis S. St. Laurent* and *Healy* Extended Continental Shelf expeditions, Arctic Ocean, 3 August – 16 September.

Date	***Healy***			***Louis S. St. Laurent***	
[2010]	**Location**	**Activity if ice**	**Activity if NO ice**[1]	**Location**	**Activity**[2]
03-Aug	US port	*Healy* dep. Dutch Harbor			
04-Aug				Canada port	*Louis* dep. Kugluktuk
3/4-7 Aug	US EEZ	Steam to rendezvous		Can/US EEZ	Steam to rendezvous
7-12 Aug	US EEZ	break ice for Louis[3]	multibeam - AK slope	US EEZ	Survey lines in US EEZ
12-17 Aug	International/US EEZ	break ice for Louis[3]	multibeam - AK slope	International	Survey lines of interest to US outside US EEZ
17 Aug-1 Sep	International/Can EEZ	break ice for Louis[3]		International/Can EEZ	Survey lines of interest to Can[4]
17Aug-1 Sep	International/Can EEZ	Occassional sampling[5]		International/Can EEZ	Occasional CTD
17 Aug-1 Sep	International/Can EEZ	Occasional multibeam only		International/Can EEZ	Break ice for Healy
02-Sep	International	End two-ship work		International	End two-ship work
04-Sep	US Port	*Healy* port call Barrow			
2-13 Sep				International/Can EEZ	Survey lines of interest to Can[6]
13-15 Sep				Can EEZ	Steam plus refuel (?)
16-Sep				Canada Port	*Louis* port call Kugluktuk

🟦 Indicates activity in US EEZ

🟪 Indicates activity in International waters or Canadian EEZ

[1] Assume two-ship operations for 17 Aug-2 Sep

[2] Assume seismic data acquisition unless otherwise noted

[3] Also acquire multibeam data

[4] Not all of these lines will be collected; final track decisions will depend on ice conditions in August, 2010

[5] Dredging and/or coring

[6] Northern part of line D may require two-ship operations

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 and narwhal), mysticetes (baleen whales), and carnivora (pinnipeds and polar bears). Cetaceans and pinnipeds (except walruses) are the subject of this IHA Application to NMFS. In the U.S., the walrus and polar bear are managed by the U.S. Fish and Wildlife Service. beast

Marine mammal species under the jurisdiction of NMFS which are known to or may occur in the seismic survey area include nine cetacean species and four species of pinnipeds (Table 4). Three of these species, the bowhead, humpback and fin whales, are listed as “Endangered” under the ESA. Bowhead whale is more common in the survey area than other endangered species. Based on a small number of sightings in the Chukchi Sea, the fin whale is unlikely to be encountered along the planned trackline in the Arctic Ocean. Humpback whales are 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. 2009). The only known occurrence of humpback whale in the Beaufort Sea was a single sighting of a cow and calf reported and photographed in 2007 (Green et al. 2007). Based on the low number of sightings in the Chukchi and Beaufort seas, humpback whales would be unlikely to occur in the vicinity of the proposed geophysical activities.

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

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

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

Sections III and IV are integrated here to minimize repetition.

The marine mammal species under NMFS jurisdiction most likely to occur in the seismic survey area include two cetacean species (beluga and bowhead whales), and two pinniped species (ringed and bearded seals). These species however, will likely occur in low numbers and most sightings will likely occur in locations within 100 km of shore where no seismic work is planned. The marine mammal most likely to be encountered throughout the cruise is the ringed seal.

TABLE 4. The habitat, abundance (in Alaska or the north Chukchi 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*)	Offshore, Coastal, Ice edges	3710[4] 39,257[5]	Not listed	NT	II
Narwhal (*Monodon monoceros*)	Offshore, Ice edge	Rare[6]	Not listed	NT	II
Killer whale (*Orcinus orca*)	Widely distributed	Rare	Not listed	DD	II
Harbor Porpoise (*Phocoena phocoena*)	Coastal, inland waters, shallow offshore waters	Common (Chukchi) Uncommon (Beaufort)	Not listed	LC	II
Mysticetes Bowhead whale (*Balaena mysticetus*)	Pack ice & coastal	10,545[7]	Endangered	LC	I
Gray whale (*Eschrichtius robustus*) (eastern Pacific population)	Coastal, lagoons	488[8] 17,500[9]	Not listed	LC	I
Minke whale (*Balaenoptera acutorostrata*)	Shelf, coastal	Small numbers	Not listed	LC	I
Fin whale (*Balaenoptera physalus*)	Slope, mostly pelagic	Rare (Chukchi)	Endangered	EN	I
Humpback whale (*Megaptera novaeangliae*)	Shelf, coastal	Rare	Endangered	LC	–
Pinnipeds Bearded seal (*Erignathus barbatus*)	Pack ice, open water	300,000-450,000[10]	In review for listing	LC	–
Spotted seal (*Phoca largha*)	Pack ice, open water, coastal haulouts	~59,214[11]	Arctic pop. Segments not listed	DD	–
Ringed seal (*Pusa hispida*)	Landfast & pack ice, open water	18,000 [12] ~208,000-252,000[13]	In review for listing	LC	–

Species	Habitat	Abundance	ESA[1]	IUCN[2]	CITES[3]
Ribbon seal (*Histriophoca fasciata*)	Pack ice, open water	90-100,000[14]	Not listed	DD	–

[1] Endangered Species Act.

[2] Classifications are from 2009 IUCN *Red List of Threatened Species* (IUCN 2010): CR = Critically Endangered; EN = Endangered; VU = Vulnerable; NT = Near Threatened; LC = Least Concern.

[3] Convention on International Trade in Endangered Species of Wild Fauna and Flora (UNEP-WCMC 2004).

[4] Eastern Chukchi Sea stock based on 1989-1991 surveys with a correction factor (Angliss and Allen 2009)

[5] Beaufort Sea stock based on surveys in 1992 (Angliss and Allen 2009).

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

[7] Abundance of bowhead whales surveyed near Barrow, as of 2001 (George et al. 2004). Revised to 10,545 by Zeh and Punt (2005).

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

[9] Eastern North Pacific gray whale population (Rugh et al. 2008)

[10] Based on earlier estimates, no current population estimate available (Angliss and Allen 2009)

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

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

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

[14] Bering Sea population (Burns 1981a in Angliss and Allen 2009).

Odontocetes

Beluga (*Delphinapterus leucas*)

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

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

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

Beluga whales 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 (Angliss and Allen 2009). The majority of belugas in the Beaufort stock migrate into the Beaufort Sea in April or May, although some whales may pass Point Barrow as early as late March and as late as July (Braham et al. 1984; Ljungblad et al. 1984; Richardson et al. 1995).

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. During late summer and autumn, most belugas migrate westward far offshore near the pack ice (Frost et al. 1988; Hazard 1988; Clarke et al. 1993; Miller et al. 1999). Lyons et al. (2009) reported the highest beluga sighting rates during the first two weeks of September during aerial surveys in the Alaskan Beaufort Sea in 2007. Peak beluga sighting rates were reported in July in 2008 when these surveys were undertaken earlier in the year (Christi et al. 2009).

The ***eastern Chukchi Sea*** population is estimated at 3710 animals (Angliss and Allen 2009). This estimate was based on surveys conducted in 1989–1991. Survey effort was concentrated on the 170 km long Kasegaluk Lagoon where belugas are known to occur during the open-water season. The 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 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 Bering Sea (Angliss and Allen 2009).

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

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.

No beluga whales were observed during seismic projects within latitudes of this proposed project – north of 71 ºN – in 2005, 2006 and 2009 (Haley and Ireland 2006, Haley 2006, Mosher et al. 2009). Marine mammal observers did, however, record one sighting of more than two beluga whales within the southern-most latitude (71.37°N) of the proposed survey in 2008 (Geological Survey of Canada [GSC] unpubl. data, 2008). These animals were approximately 636 km east of the proposed project's location on 23 August, when members of the Beaufort Sea population were observed in the eastern Beaufort Sea (Angliss and Allen 2009).

Narwhal (*Monodon monoceros*)

Narwhals have a discontinuous arctic distribution (Hay and Mansfield 1989; Reeves et al. 2002). A large population inhabits Baffin Bay, West Greenland, and the eastern part of the Canadian Arctic archipelago, and much smaller numbers inhabit the Northeast Atlantic/East Greenland area. Population estimates for the narwhal are scarce, and the IUCN-World Conservation Union lists the species as Data

Deficient (IUCN Red List of Threatened Species 2003). Innes et al. (2002) estimated a population size of 45,358 narwhals in the Canadian Arctic although little of the area was surveyed. There are scattered records of narwhal in Alaskan waters where the species is considered extralimital (Reeves et al. 2002). No narwhals were observed during survey projects within latitudes of the area of this proposed project – north of 71 ºN - in 2005, 2006, 2008 and 2009 (Haley and Ireland 2006, Haley 2006, GSC unpubl. data 2008, Mosher et al. 2009). 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 (Angliss and Allen 2009).

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

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. 1995).

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

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

Mysticetes

Bowhead Whale (*Balaena mysticetus*)

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). Allowing for an additional census in 2001, the latest estimates are based on an annual population growth rate of 3.4% (95% CI 1.7–5%) from 1978 to 2001 and a population size (in 2001) of ~10,470 animals (George et al. 2004, recently revised to 10,545 by Zeh and Punt [2005]). Assuming a continuing annual population growth of 3.4%, the 2010 bowhead population may number around 14,247 animals. The large increases in population estimates that occurred from the late 1970s to the early 1990s were partly a result of actual population growth, but were also partly attributable to improved census techniques (Zeh et al. 1993). Although apparently recovering well, the BCB bowhead population is currently listed as endangered under the ESA and is classified as a strategic stock by NMFS and depleted under the MMPA (Angliss and Allen 2009).

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

The 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 mid-summer. 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 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, 2008; Greene et al. 2007). Consistent with this, Nuiqsut whalers have stated that the earliest arriving bowheads have apparently reached the Cross Island area earlier in recent years than formerly (T. Napageak, pers. comm.). In 2007 the MMS and the National Marine Mammal Laboratory (NMML) initiated the Bowhead Whale Feeding Ecology Study (BOWFEST) focusing on late summer oceanography and prey densities relative to bowhead distribution (Rugh 2009).

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

In autumn, westward-migrating bowhead whales typically reach the Kaktovik and Cross Island areas in early September, when the subsistence hunts for bowheads typically begin in those areas (Kaleak 1996; Long 1996; Galginaitis and Koski 2002; Galginaitis and Funk 2004, 2005; Koski et al. 2005). In recent years the hunts at those two locations have usually ended by mid- to late September.

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

Over the years, local residents have reported small numbers of bowhead whales feeding off Barrow or in the pack ice off Barrow during the summer. Bowhead whales that are thought to be part of the Western Arctic stock may also occur in small numbers in the Bering and Chukchi seas during the summer (Rugh et al. 2003). Thomas et al. (2009) reported bowhead sightings during summer aerial surveys in nearshore areas of the Chukchi Sea from 2006-2008. All sightings were recorded in the northern portion of the study area north of 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 (LGL unpubl. data). Observers from the NMML reported 19 summer bowhead sightings in the Chukchi Sea during aerial surveys from 26 June through 26 July 2009 suggesting that some bowheads may summer in the Chukchi Sea (unpublished data available at http://www.afsc.noaa.gov/NMML/cetacean/bwasp/flights_COMIDA.php). Only one bowhead sighting was reported later in the year (22 August) during similar surveys in 2008. 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 during Arctic cruises in 2005, 2006, 2008 and 2009 (Haley and Ireland 2006; Haley 2006, GSC unpubl. data 2008, Mosher et al. 2009).

Most spring-migrating bowhead whales will likely pass through the Chukchi and Beaufort seas prior to the start of the proposed survey in August. However, a few whales that may remain in the Chukchi Sea or in the Barrow area during the summer could be encountered by transiting vessels. The potential for encounters with bowhead whales would be more likely during the westward fall migration in September. Much of the proposed survey area however, is in deep water well north of the known bowhead migration corridor and few if any bowheads are likely to be encountered during the survey activity.

Gray Whale (*Eschrichtius robustus*)

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

Eastern Pacific gray whales calve in the protected waters along the west coast of Baja California and the east coast of the Gulf of California from January to April (Swartz and Jones 1981; Jones and Swartz 1984). At the end of the calving season, most of these gray whales migrate about 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 a 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 MMS and industry from 1979 to 1997. However, during September 1998, small numbers of gray whales were sighted on several occasions in the central Alaskan Beaufort Sea (Miller et al. 1999; Treacy 2000). More recently a single sighting of a gray whale was made on 1 August 2001 near the Northstar production island (Williams and Coltrane 2002). Several gray whale sightings were reported during both vessel-based and aerial surveys in the Beaufort Sea in 2006 and 2007 (Jankowski et al. 2008; Lyons et al. 2009) and during vessel-based surveys in 2008 (Savarese et al. 2009). Several single gray whales have been seen farther east in the Canadian Beaufort Sea (Rugh and Fraker 1981; LGL Ltd., unpubl. data), indicating that small numbers must travel through the Alaskan Beaufort during some summers. In recent years, ice conditions have become lighter near Barrow, and gray whales may have become more common there and perhaps in the Beaufort Sea. In the springs of 2003 and 2004, a few tens of gray whales were seen near Barrow by early-to-mid June (LGL Ltd and NSB-DWM, unpubl. data). However, no gray whales were sighted during cruises north of Barrow in 2002, 2005 2006, 2008 or 2009 (Harwood et al. 2005; Haley and Ireland 2006; Haley 2006, GSC unpubl. data 2008, Mosher et al. 2009).

Small numbers of gray whales could be encountered by survey vessels during transit periods. Gray whales ocurr in relatively shallow waters where they feed on benthic invertebrates and they are not likely to occur in the deeper water of the proposed survey area.

Minke Whale (*Balaenoptera acutorostrata*)

Minke whales have a cosmopolitan distribution at ice-free latitudes (Stewart and Leatherwood 1985), and also occur in some marginal ice areas. Angliss and Allen (2009) recognize two minke whale stocks in U.S. waters: (1) the Alaska stock, and (2) the California/Oregon/Washington stock. There is no abundance estimate for the Alaska stock. Provisional estimates of Minke whale abundance based on surveys in 1999 and 2000 are 810 and 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.

Minke whales range into the Chukchi Sea and a few sightings have been reported in the Beaufort Sea in recent years (Funk et al. 2009). The level of Minke whale use of the Chukchi Sea is unknown. Leatherwood et al. (1982, *in* Angliss and Allen 2009) indicated that Minke whales are not considered abundant in any part of their range, but that some individuals venture north of the Bering Strait in summer. Reiser et al. (2008) reported eight and five Minke whale sightings in 2006 and 2007, respectively, during vessel-based surveys in the Chukchi Sea, and Haley et al. (2009) reported 26 Minke whale sightings during similar vessel-based surveys in the Chukchi Sea in 2008. Savarese et al. (2009) reported two Minke whale sightings in the Beaufort Sea during vessel-based operations in 2006-2008. No Minke whale sighting were reported during Arctic cruises in 2005, 2006, 2008 or 2009 (Haley and Ireland 2006; Haley 2006, GSC unpubl. data 2008, Mosher et al. 2009). Minke whales sometimes occur in areas with minimal ice cover and it is possible though unlikely that a few Minke whales could be encountered during the proposed survey activities.

Fin Whale (*Balaenoptera physalus*)

Fin whales are widely distributed in all the world's oceans (Gambell 1985), but typically occur in temperate and polar latitudes and less frequently in the tropics (Reeves et al. 2002). Fin whales feed in northern latitudes during the summer where their prey includes plankton as well as schooling pelagic fish, such as herring, sandlance, and capelin (Jonsgård 1966a,b; Reeves et al. 2002). The North Pacific population summers from the Chukchi Sea in small numbers to California (Gambell 1985), but does not range into the Alaskan Beaufort Sea or waters of the northern Chukchi Sea. Reliable estimates of fin whale abundance in the Northeast Pacific are not available (Angliss and Allen 2009). Provisional estimates of fin whale abundance in the central-eastern and south-eastern Bering Sea are 3,368 and 683, respectively (Moore et al. 2002). Zerbini et al. (2006) reported numerous fin whale sightings from Kodiak Island to the central Aleutian Islands. Fin whale is listed as endangered under the ESA and by IUCN, is classified as a strategic stock by NMFS, and is a CITES Appendix I species (Table 4).

No estimates for fin whale abundance during the summer in the Chukchi Sea are available. Recently a fin whale was recorded in the southern Chukchi Sea during vessel-based surveys in 2006 (LGL unpublished data), and three fin whale sightings were recorded in the Chukchi Sea in 2008 (Haley et al. 2009). NMML observers also observed and photographed a fin whale off Pt. Lay in 2008 during the COMIDA aerial survey program. Fin whales were not recorded during vessel-based or aerial surveys in the Beaufort Sea in 2006-2008 (Savarese et al. 2009; Christi et al. 2009), and were not reported during arctic cruises in 2005, 2006, 2008 or 2009 (Haley and Ireland 2006; Haley 2006, GSC unpubl. data 2008, Mosher et al. 2009). Fin whale would be unlikely to occur in the proposed geophysical survey area.

Humpback Whale (*Megapter novaeangliae*)

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

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

Humpbacks feed on euphausiids, copepods, and small schooling fish, notably herring, capelin, and sandlance (Reeves et al. 2002). As with other baleen whales, the food is trapped or filtered when large amounts of water taken into the mouth and the expanded throat area are forced out through the baleen plates. Individual humpback whales can often be identified by distinctive patterns on the tail flukes. They are frequently observed breaching or engaged in other surface activities. Adult male and female humpback whales average 14 and 15 m (46 and 49 ft) in length, respectively (Wynne 1997). Humpbacks have large, robust bodies and long pectoral flippers which may reach 1/3 of their body length. The dorsal fin is variable in shape and located well back toward the posterior 1/3 of the body on a hump which is particularly noticeable when the back is arched during a dive (Reeves et al. 2002).

Angliss and Allen (2009) reported that at least three humpback whale populations have been identified in the North Pacific. Two of these stocks may be relevant to the Chukchi Sea portion of the project area. The Central North Pacific stock winters in waters near Hawaii and migrates to British Columbia, Southeast Alaska, and Prince William Sound to Unimak Pass to feed during the summer. The Western North Pacific stock winters off the coast of Japan and probably migrates to the Bering Sea to feed during the summer. There may be some overlap between the Central and Western North Pacific stocks.

Humpback whale sightings in the Bering Sea have been recorded southwest of St. Lawrence Island, the southeastern Bering Sea, and north of the central Aleutian Islands (Moore et al. 2002; Angliss and Allen 2009). Recently there have been sightings of humpback whales in the Chukchi Sea and a single sighting in the Beaufort Sea (Green et al. 2007). Haley et al (2009) reported four humpback whales during vessel-based surveys in the Chukchi Sea in 2007 and two sightings in 2008. NMML observers recorded a humpback whale during aerial surveys in the Chukchi Sea in 2009. Green et al. (2007) reported and photographed a humpback whale cow/calf pair east of Barrow near Smith Bay in 2007. No humpback whales were reported during cruises in the Arctic Ocean in 2005, 2006, 2008 or 2009 (Haley and Ireland 2006; Haley 2006, GSC unpubl. data 2008, Mosher et al. 2009). 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 could occur in the Chukchi Sea and possibly in the Beaufort Sea but would be unlikely to occur in the deep offshore waters of the proposed survey area.

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 (e.g., Harwood et al. 2005). No reliable estimate of bearded seal abundance is available for the Chukchi and Beaufort seas (Angliss and Allen 2009). The Alaska stock of bearded seals is not classified by NMFS as endangered or a strategic stock, however there has recently been a petition to list this and other arctic seals due to the potential impact to seal habitats resulting from current warming trends (CBD 2008). A finding by NMFS to determine whether bearded seals should be listed is pending.

In Alaskan waters, bearded seals occur over the continental shelves of the Bering, Chukchi, and Beaufort seas (Burns 1981b). The Alaska stock of bearded seals may consist of about 300,000–450,000 individuals based on earlier accounts but no current population estimates are available (MMS 1996; Angliss and Allen 2009). Bengtson et al. (2005) reported bearded seal densities in the Chukchi Sea ranging from 0.07 to 0.14 seals/km^2 in 1999 and 2000, respectively. No population estimates could be calculated because these densities were not adjusted for haulout behavior. Bearded seals were more common in offshore pack ice with the exception of high bearded seal numbers observed near the shore south of the survey area near Kivalina. Haley et al. (2009) reported bearded seal densities up to 0.022 to 0.064 seals/km^2 in summer and fall, respectively during vessel-based surveys in the Chukchi Sea in 2006-2008. These densities were lower than those reported by Bengtson et al. (2005) but are not directly comparable because the latter densities were based on aerial surveys of seals at ice holes in late May and early June.

In the Beaufort Sea, Savarese et al. (2009) reported bearded seal densities up to 0.028 and 0.035 seal/km^2 in the summer and fall, respectively during vessel-based surveys in 2006-2008. Haley and Ireland (2006) reported no bearded seal sightings during an arctic cruise from the *Healy* in 2005 along ~361 km of monitored trackline within the latitudes of the proposed survey (71–74 °N). Five bearded seal sightings were reported during the 2006 *Healy* cruise along 622 km of trackline within 71–74 °N (Haley 2006).

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

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

In some areas, bearded seals are associated with the ice year-round; however, they usually move shoreward into open water areas when the pack ice retreats to areas with water depths greater than 200 m. During the summer, when the Bering Sea is ice-free, the most favorable bearded seal habitat is found in the central or northern Chukchi Sea along the margin of the pack ice. Suitable habitat is more limited in the Beaufort Sea where the continental shelf is narrower and the pack ice edge frequently occurs seaward of the shelf and over water too deep for benthic feeding. The preferred habitat in the western and central Beaufort Sea during the open-water period is the continental shelf seaward of the scour zone. 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.

Small numbers of bearded seals would likely be encountered during the proposed geophysical survey. Bearded seals could also be encountered during transit periods in shallow areas closer to shore.

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).

In the Chukchi Sea, Kasegaluk Lagoon is an important area for spotted seals. Spotted seals haul out in the area from mid-July until freeze-up in late October or November. Frost and Lowry (1993) reported a maximum count of about 2200 spotted seals in the lagoon during aerial surveys. No spotted seals were recorded along the shore south of Pt. Lay. Based on satellite tracking data, Frost and Lowry (1993) reported that spotted seals at Kasegaluk Lagoon spent 94% of the time at sea. Extrapolating the count of hauled-out seals to account for seals at sea would suggest a Chukchi Sea population of about 36,000 animals.

An early estimate of the size of the world population of spotted seals was 370,000–420,000, and the size of the Bering Sea population, including animals in Russian waters, was estimated to be 200,000–250,000 animals (Bigg 1981). The total number of spotted seals in Alaskan waters is not known (Angliss and Allen 2009), but the estimate is most likely between several thousand and >50,000 (Rugh et al. 1997).

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, Angliss and Allen (2009) estimated the Alaskan population at 59,214 animals. The Alaska stock of spotted seals is not classified as endangered or as a strategic stock by NMFS (Hill and DeMaster 1998). In response to a petition to list spotted seals under the Endangered Species Act (CBD 2008), NMFS concluded that only the southern distinct population segment (DPS) which occurs in Japan, outside of U.S. waters, merited listing.

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

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). Numbers seen per year ranged from zero (in 1998 and 2000) to four (in 1999). More recently Green et al. (2007) reported 46 spotted seal sightings during barge operations between West Dock and Cape Simpson. Most sightings occurred from western Harrison Bay to Cape Simpson with only one sighting offshore of the Colville River delta. No spotted seals were recorded from the *Healy* during arctic cruises in 2005 or 2006 (Haley and Ireland 2006; Haley 2006). Spotted seals would be unlikely to occur in the proposed survey area in 2010 although some spotted seals could be encountered during transit periods.

Ringed Seal (*Phoca hispida*)

Ringed seals have a circumpolar distribution and occur in all seas of the Arctic Ocean (King 1983). They are closely associated with ice, and in the summer they often occur along the receding ice edges or farther north in the pack ice. In the North Pacific, they occur in the southern Bering Sea and range south to the seas of Okhotsk and Japan. They are found throughout the Beaufort, Chukchi, and Bering seas (Angliss and Allen 2009).

During winter, ringed seals occupy landfast ice and offshore pack ice of the Bering, Chukchi and Beaufort seas. In winter and spring, the highest densities of ringed seals are found on stable shorefast ice. However, in some areas where there is limited fast ice but wide expanses of pack ice, including the Beaufort Sea, Chukchi Sea and Baffin Bay, total numbers of ringed seals on pack ice may exceed those on shorefast ice (Burns 1970; Stirling et al. 1982; Finley et al. 1983).

Ringed seals maintain breathing holes in the ice and occupy lairs in accumulated snow (Smith and Stirling 1975). They give birth in lairs from mid-March through April, nurse their pups in the lairs for 5–8 weeks, and mate in late April and May (Smith 1973; Hammill et al. 1991; Lydersen and Hammill 1993).

Ringed seals are year-round residents in the northern Chukchi and Beaufort seas and ringed seal is the most frequently encountered seal species in the area. No estimate for the size of the Alaska ringed seal stock is currently available (Angliss and Allen 2009). Past ringed seal population estimates in the Bering-Chukchi-Beaufort area ranged from 1–1.5 million (Frost 1985) to 3.3–3.6 million (Frost et al. 1988). Frost and Lowry (1981) estimated 80,000 ringed seals in the Beaufort Sea during summer and 40,000 during winter. More recent estimates based on extrapolation from aerial surveys and on predation estimates for polar bears (Amstrup 1995) suggest an Alaskan Beaufort Sea population 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 study area in 1999. The Alaska stock of ringed seals is not endangered, and is not classified as a strategic stock by NMFS however there has recently been a petition to list this and other arctic seals due to the potential impact to seal habitats resulting from current warming trends (CBD 2008). A finding by NMFS to determine whether ringed seals should be listed is pending.

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

Moulton et al. (2002) reported ringed seal densities (uncorrected) ranging from 0.43 to 0.63 seal per km^2 in water over 3 m in depth during spring aerial surveys in the central Alaskan Beaufort Sea. Densities were higher in nearshore than offshore locations. Ringed seal was the most frequently sighted seal identified to species from the *Healy* during arctic cruises in 2005 (3 sightings; Haley and Ireland 2006) and 2006 (10 sightings; Haley 2006). These sightings occurred over 361 km and 622 km, respectively along monitored tracklines within the latitudes of the proposed survey (71–74 °N). Ringed seals likely would 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. 1981). 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 National Marine Mammal Laboratory, 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 2006-2009 with only three sightings among 1778 sightings of seals identified to species (Haley et al. 2009). Ribbon seals do not normally occur in the Beaufort Sea, however, three recent ribbon seal sightings were reported during vessel-based activities in the Beaufort Sea in 2007-2008 (Savarese et al 2009).

In response to a petition to list ribbon seal under the Endangered Species Act (CBD 2007), a recent announcement by NMFS indicated that listing of ribbon seal was not warranted at this time (NMFS 2008a). Ribbon seals were not reported during the arctic Healy cruises in 2005 and 2006, and would be unlikely to occur in the proposed survey area.

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.

The USGS 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 August-September 2010.

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 by the airgun array used during the surveys. "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. No take by serious injury is anticipated, given the nature of the planned operations and the mitigation measures that are planned (see § XI, "Mitigation Measures"). No lethal takes are expected.

VI. NUMBERS OF MARINE MAMMALS THAT MAY BE TAKEN

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

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

VII. ANTICIPATED IMPACT ON SPECIES OR STOCKS

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

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

Summary of Potential Effects of Airgun Sounds

The effects of sounds from airguns might include one or more of the following: tolerance, masking of natural sounds, behavioral disturbance, and at least in theory, temporary or permanent hearing impairment, or non-auditory physical effects (Richardson et al. 1995). Given the moderate size of the sources planned for the proposed project, plus mitigation measures to be applied, it is unlikely that there would be any cases of temporary or especially permanent hearing impairment, or non-auditory physical effects.

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 D (3). Numerous studies have also shown that marine mammals at distances more than a few kilometers from operating seismic vessels often show no apparent response—see Appendix D (5). 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

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. 2008). 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 D (4).

Disturbance Reactions

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

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

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

Baleen Whales.—Baleen whales generally tend to avoid operating airguns, but avoidance radii are quite variable. Whales are often reported to show no overt reactions to pulses from large arrays of airguns at distances beyond a few kilometers, even though the airgun pulses remain well above ambient noise levels out to much longer distances. However, as reviewed in Appendix D (5), baleen whales exposed to strong noise pulses from airguns often react by deviating from their normal migration route and/or interrupting their feeding and moving away. In the case of the migrating gray and bowhead whales, the observed changes in behavior appeared to be of little or no biological consequence to the animals. They simply avoided the sound source by displacing their migration route to varying degrees, but within the natural boundaries of the migration corridors.

Studies of gray, bowhead, and humpback whales have determined that received levels of pulses in the 160–170 dB re 1 μPa rms range seem to cause obvious avoidance behavior in a substantial fraction of the animals exposed. In many areas, seismic pulses from large arrays of airguns diminish to those levels at distances ranging from 4.5 to 14.5 km from the source. A substantial proportion of the baleen whales within those distances may show avoidance or other strong disturbance reactions to the airgun array. Subtle behavioral changes sometimes become evident at somewhat lower received levels, and recent studies reviewed in Appendix D (5) have shown that some species of baleen whales, notably bowhead and humpback whales, at times show strong avoidance at received levels lower than 160–170 dB re 1 μPa rms. Bowhead whales migrating west across the Alaskan Beaufort Sea in autumn, in particular, are unusually responsive, with substantial avoidance occurring out to distances of 20–30 km from a medium-sized airgun source (Miller et al. 1999; Richardson et al. 1999; see Appendix D [5]). However, more recent research on bowhead whales (Miller et al. 2005; Lyons et al. 2009; Christi et al. 2009) corroborates earlier evidence that, during the summer feeding season, bowheads are not as sensitive to seismic sources. In summer, bowheads typically begin to show avoidance reactions at a received level of about 160–170 dB re 1 μPa rms (Richardson et al. 1986; Ljungblad et al. 1988; Miller et al. 1999). The USGS project will be conducted primarily during fall migration at locations > 200 nmi. offshore, well north of the known bowhead migration corridor. Recent evidence suggests that some bowheads feed during migration and feeding bowheads might be encountered in the central Alaskan Beaufort Sea during transit periods to and from Barrow (Lyons et al. 2009; Christi et al. 2009). The primary bowhead summer feeding grounds however, are far to the east in the Canadian Beaufort Sea,

Malme et al. (1986, 1988) studied the responses of feeding eastern gray whales to pulses from a single 100 in^3 airgun off St. Lawrence Island in the northern Bering Sea. They estimated, based on small sample sizes, that 50% of feeding gray whales ceased feeding at an average received pressure level of 173 dB re 1 μPa on an (approximate) rms basis, and that 10% of feeding whales interrupted feeding at received levels of 163 dB. Those findings were generally consistent with the results of experiments conducted on larger numbers of gray whales that were migrating along the California coast, and on observations of Western Pacific gray whales feeding off Sakhalin Island, Russia (Johnson 2002).

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

Toothed Whales.—Little systematic information is available about reactions of toothed whales to noise pulses. Few studies similar to the more extensive baleen whale/seismic pulse work summarized above and (in more detail) in Appendix D have been reported for toothed whales. However, systematic work on sperm whales is underway (Tyack et al. 2003), and there is an increasing amount of information about responses of various odontocetes to seismic surveys based on monitoring studies (e.g., Stone 2003; Smultea et al. 2004; Moulton and Miller 2005).

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, there have been indications that small toothed whales sometimes move away, or maintain a somewhat greater distance from the vessel, when a large array of airguns is operating than when it is silent (e.g., Goold 1996a,b,c; Calambokidis and Osmek 1998; Stone 2003).

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. With the presently-planned source, such levels would be limited to distances less than 200 m of the 3-airgun array. The reactions of belugas to the USGS survey are likely to be more similar to those of free-ranging belugas exposed to airgun sound (Miller et al. 2005) 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.

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 D (5). 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). Even if reactions of the species occurring in the present study area are as strong as those evident in the telemetry study, reactions are expected to be confined to relatively small distances and durations, with no long-term effects on pinniped individuals or populations.

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 D (6) and summarized here,

- the 180 dB criterion for cetaceans is probably quite precautionary, i.e., lower than necessary to avoid temporary threshold shift (TTS), let alone permanent auditory injury, at least for belugas and delphinids.
- the minimum sound level necessary to cause permanent hearing impairment is higher, by a variable and generally unknown amount, than the level that induces barely-detectable TTS.
- the level associated with the onset of TTS is often considered to be a level below which there is no danger of permanent damage.

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

Several aspects of the planned monitoring and mitigation measures for this project are designed to detect marine mammals occurring near the airguns to avoid exposing them to sound pulses that might, at least in theory, cause hearing impairment [see § XI, 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, and the planned monitoring and mitigation measures (see below). The following subsections discuss in somewhat more detail the possibilities of TTS, permanent threshold shift (PTS), and non-auditory physical effects.

Temporary Threshold Shift (TTS).—TTS is the mildest form of hearing impairment that can occur during exposure to a strong sound (Kryter 1985). While experiencing TTS, the hearing threshold rises and a sound must be stronger in order to be heard. At least in terrestrial mammals, TTS can last from minutes or hours to (in cases of strong TTS) days. For sound exposures at or somewhat above the TTS threshold, hearing sensitivity in both terrestrial and marine mammals recovers rapidly after exposure to the noise ends. Few data on sound levels and durations necessary to elicit mild TTS have been obtained for marine mammals, and none of the published data concern TTS elicited by exposure to multiple pulses of sound.

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

For baleen whales, there are no data, direct or indirect, on levels or properties of sound that are required to induce TTS. However, no cases of TTS are expected given the moderate size of the source, and the strong likelihood that baleen whales (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 D (6)].

A marine mammal within a radius of ≤100 m (≤328 ft) around a typical large array of operating airguns might be exposed to a few seismic pulses with levels of ≥205 dB, and possibly more pulses if the mammal moved with the seismic vessel. The received sound levels will be reduced for the proposed three-gun array to be used during the current survey compared to the larger arrays thus reducing the potential for TTS for the proposed survey. (As noted above, most cetacean species tend to avoid operating airguns, although not all individuals do so.) However, several of the considerations that are relevant in assessing the impact of typical seismic surveys with arrays of airguns are not directly applicable here:

- "Ramping up" (soft start) is standard operational protocol during startup of large airgun arrays in many jurisdictions. Ramping up involves starting the airguns in sequence, usually commencing with a single airgun and gradually adding additional airguns.
- 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. For the proposed project, the seismic survey will be in deep water where the radius of influence and duration of exposure to strong pulses is smaller compared to shallow locations.
- 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 (re 1 µP @ 1 m rms) safety zone in deep water are expected to extend ~483 m and 153 m, respectively, from the airgun array which 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 slight TTS if no mitigation action (shutdown) were taken.

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. All airgun activity will occur in water depths ranging from ~2000 to 4000 m. Sound level radii of the proposed three-airgun array were measured in 2009 during a seismic calibration experiment (Mosher et al. 2009, Roth and Schmidt 2010). A transmission loss model was then constructed assuming spherical (20LogR) spreading and using the source level estimate (235 dB re 1 µPa 0-peak; 225 dB re 1 µPa rms) from the measurements. The use of 20LogR spreading fit the data well out to ~1 km where variability in measured values increased (see Appendix B for more details and a figure of the transmission loss model compared to the measurement data). Additionally, the Gundalf® modeling package was used to model the airgun array and estimated a source level output of 236.7 dB 0-peak (226.7 dB rms). Using this slightly stronger source level estimate and 20LogR spreading the 180 and 190 dB rms radii are estimated to be 216 m and 68 m, respectively. As a conservative measure for the proposed safety radii, the sound-level radii indicated by the empirical data and source models have been increased to 500 m for the 180-dB isopleth and to 100 m for the 190-dB isopleth (Table 2). These distances will be used as power down/ shutdown criteria as described in § XI, MITIGATION MEASURES, below. Furthermore, established 190 and 180 dB re 1 µPa (rms) criteria are ***not*** considered to be the levels above which TTS might occur. Rather, they are the received levels above which, in the view of a panel of bioacoustics specialists convened by NMFS before TTS measurements for marine mammals started to become available, one could not be certain that there would be no injurious effects, auditory or otherwise, to marine mammals. As summarized above, data that are now available imply that TTS is unlikely to occur unless odontocetes are exposed to airgun pulses much stronger than 180 dB re 1 µPa rms. Since no bow-riding species occur in the study area, it is unlikely such exposures will occur.

Permanent Threshold Shift (PTS).—When PTS occurs, there is physical damage to the sound receptors in the ear. In some cases, there can be total or partial deafness, whereas in other cases, the animal has an impaired ability to hear sounds in specific frequency ranges.

There is no specific evidence that exposure to pulses of airgun sound can cause PTS in any marine mammal, even with large arrays of airguns. However, given the possibility that mammals close to an airgun array might incur TTS, there has been further speculation about the possibility that some individuals occurring very close to airguns might incur PTS. Single or occasional occurrences of mild TTS are not indicative of permanent auditory damage in terrestrial mammals. Relationships between TTS and PTS thresholds have not been studied in marine mammals, but are assumed to be similar to those in humans and other terrestrial mammals. PTS might occur at a received sound level at least several decibels above that inducing mild TTS if the animal were exposed to the strong sound pulses with very rapid rise time—see Appendix D (6).

It is highly unlikely that marine mammals could receive sounds strong enough (and over a sufficient duration) to cause permanent hearing impairment during a project employing the medium-sized airgun source planned here. For the proposed project, marine mammals are unlikely to be exposed to received levels of seismic pulses strong enough to cause TTS. Given the higher level of sound necessary to cause PTS, it is even less likely that PTS could occur. In fact, even the levels immediately adjacent to the airgun may not be sufficient to induce PTS, especially because a mammal would not be exposed to more than one strong pulse unless it swam immediately alongside the airgun for a period longer than the inter-pulse interval. 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 minimize the already-minimal probability of exposure of marine mammals to sounds strong enough to induce PTS.

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

Until recently, it was assumed that diving marine mammals are not subject to the bends or air embolism. This possibility was first explored at a workshop (Gentry [ed.] 2002) held to discuss whether the stranding of beaked whales in the Bahamas in 2000 (Balcomb and Claridge 2001; NOAA and USN 2001) might have been related to bubble formation in tissues caused by exposure to noise from naval sonar. However, the opinions were inconclusive. Jepson et al. (2003) first suggested a possible link between mid-frequency sonar activity and acute and chronic tissue damage that results from the formation *in vivo* of gas bubbles, based on the beaked whale stranding in the Canary Islands in 2002 during naval exercises. Fernández et al. (2005a) showed those beaked whales did indeed have gas bubble-associated lesions as well as fat embolisms. Fernández et al. (2005b) also found evidence of fat embolism in three beaked whales that stranded 100 km north of the Canaries in 2004 during naval exercises. Examinations of several other stranded species have also revealed evidence of gas and fat embolisms (e.g., Arbelo et al. 2005; Jepson et al. 2005a; Méndez et al. 2005). Most of the afflicted species were deep divers. There is speculation that gas and fat embolisms may occur if cetaceans ascend unusually quickly when exposed to aversive sounds, or if sound in the environment causes the destabilization of existing bubble nuclei (Potter 2004; Arbelo et al. 2005; Fernández et al. 2005a; Jepson et al. 2005b). Even if gas and fat embolisms can occur during exposure to mid-frequency sonar, there is no evidence that that type of effect occurs in response to airgun sounds. Also, most evidence for such effects have been in beaked whales, which do not occur in the proposed 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. However, the association of mass strandings of beaked whales with naval exercises and, in one case, an L-DEO seismic survey, has raised the possibility that beaked whales exposed to strong pulsed sounds may be especially susceptible to injury and/or behavioral reactions that can lead to stranding. Appendix D (6.3) provides additional details.

Seismic pulses and mid-frequency sonar pulses are quite different. Sounds produced by airgun arrays are broadband with most of the energy below 1 kHz. Typical military mid-frequency sonars operate at frequencies of 2–10 kHz, generally with a relatively narrow bandwidth at any one time. Thus, it is not appropriate to assume that there is a direct connection between the effects of military sonar and seismic surveys on marine mammals. However, evidence that sonar pulses can, in special circumstances, lead to physical damage and mortality (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.

In Sept. 2002, there was a stranding of two Cuvier's beaked whales in the Gulf of California, Mexico, when the L-DEO vessel *Maurice Ewing* was operating a 20-airgun, 8490 in^3 array in the general area. The link between the stranding and the seismic surveys was inconclusive and not based on any physical evidence (Hogarth 2002; Yoder 2002). Nonetheless, that plus the incidents involving beaked whale strandings near naval exercises suggests a need for caution in conducting seismic surveys in areas occupied by beaked whales. However, no beaked whales are found within this project area and the planned monitoring and mitigation measures are expected to minimize any possibility for mortality of other species.

Possible Effects of Chirp Echo Sounder Signals

A Knudsen 320BR Plus sounder will be operated from the source vessel at nearly all times during the planned study. Details about the equipment are provided in Appendix B. The Knudsen 320BR produces sound pulses with lengths of up to 24 ms every 0.5 to ~8 s, depending on water depth. The energy in the sound pulses emitted by the Chirp echo sounder is at moderately high frequency. The Knudsen can be operated with either a 3.5 kHz transducer, for sub-bottom profiling, or a 12 kHz transducer for sounding. The lower frequency (3.5 kHz) transducer is not installed and will not be used. The conical beamwidth for the 12 kHz transducer is 30°, and is directed downward.

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

Navy sonars that have been linked to avoidance reactions and stranding of cetaceans (1) generally are more powerful than the Knudsen 320 BR operating with the 12 kHz transducer, (2) have longer pulse duration, and (3) are directed close to horizontally vs. downward for the Knudsen 320. The area of possible influence of the Chirp echo sounder is much smaller—a narrow conical beam spreading downward from the vessel. Marine mammals that encounter the sounder at close range are unlikely to be subjected to repeated pulses because of the narrow width of the beam, and will receive only small amounts of pulse energy because of the short pulses.

Masking

Marine mammal communications will not be masked appreciably by the Chirp echo sounder signals given its relatively low duty cycle, directionality, and the brief period when an individual mammal is likely to be within its beam. Belugas can, however, hear sounds ranging from 1.2 to 120 kHz, their peak sensitivity is ~10-15 kHz, overlapping with the 12 kHz signals (Fay 1988). Some level of masking could result for belugas whales in close proximity to the survey vessel during brief periods of exposure to the sound. However masking is unlikely to be an issue for beluga whales because belugas are likely to avoid survey vessels. The 12-kHz frequency signals will not overlap with the predominant low frequencies in baleen whale calls, thus reducing potential for masking in this group.

Behavioral Responses

Marine mammal behavioral reactions to pulsed sound sources from an active airgun array are discussed above, and responses to the echo sounder are likely to be similar to those for other pulsed sources if received at the same levels. When the 12 kHz transducer is in operation, the behavioral responses to the Knudsen 320BR are expected to be similar to those reactions to the active airgun array (as discussed above). NMFS (2001) has concluded that momentary behavioral reactions “do not rise to the level of taking”. Thus, brief exposure of cetaceans to small numbers of signals from the sounder would not result in a “take” by harassment.

Hearing Impairment and Other Physical Effects

When the 12-kHz transducer is operating, the pulses are brief and concentrated in a downward beam. A marine mammal would be in the beam of the sounder only briefly, reducing its received sound energy. Thus, it is unlikely that the Chirp echo sounder produces pulse levels strong enough to cause hearing impairment or other physical injuries even in an animal that is (briefly) in a position near the source.

The Knudsen 320BR will be operated simultaneously with the airgun array. Many marine mammals will move away in response to the approaching higher-power sources or the vessel itself before the mammals would be close enough for there to be any possibility of effects from the Chirp echo sounder (Appendix D). In the case of mammals that do not avoid the approaching vessel and its various sound sources, mitigation measures that would be applied to minimize effects of the higher-power sources would further reduce or eliminate any minor effects of the echo sounder.

Possible Effects of Chirp Sub-bottom Profiler

A Knudsen 3260 sub-bottom profiler will be operated from the *Louis S. St. Laurent* in open water when the *Louis S. St. Laurent* is not working in tandem with the *Healy*. The Knudsen’s transducer will be towed behind the *Louis S. St. Laurent.* Details about the equipment are provided in Appendix B. The chirp system has a maximum 7.2 kW transmit capacity into the towed array and generally operates at 3–5 kHz. The energy from the towed unit is directed downward by an array of eight transducers in a conical beamwidth of 80°. The interval between pulses will be no less than one pulse per second. Sub-bottom profilers of that frequency can produce sound levels of 200-230 dB re 1 µPa at 1 m (Richardson et al. 1995).

Masking

Marine mammal communications will not be masked appreciably by the sub-bottom profiler signals given its relatively low duty cycle, directionality, and the brief period when an individual mammal is likely to be within its beam. In the case of most odontocetes, the 3–5 kHz chirp signals do not overlap with the predominant frequencies in their calls, which would avoid significant masking. Beluga whale is the only odontocete anticipated in the area of the proposed survey. Though belugas can hear sounds ranging from 1.2 to 120 kHz, their peak sensitivity is ~10-15 kHz, not overlapping with the 3–5 kHz signals (Fay 1988). The frequency of the low-energy chirp profiler signals does not overlap with the predominant low frequencies in baleen whale calls, further reducing potential for masking.

Behavioral Responses

Marine mammal behavioral reactions to other pulsed sound sources are discussed above, and responses to the sub-bottom profiler are likely to be similar to those for other pulsed sources if received at the same levels. However, the pulsed signals from the towed 3–5 kHz chirp sub-bottom profiler are weaker than those from the airgun array. Therefore, behavioral responses are not expected unless marine mammals are close to the source. NMFS (2001) has concluded that momentary behavioral reactions "do not rise to the level of taking". Thus, brief exposure of cetaceans to small numbers of signals from the sub-bottom profiler would not result in a "take" by harassment.

Hearing Impairment and Other Physical Effects

The pulses from the chirp profiler are brief and directed downward. A marine mammal would be in the beam of the sub-bottom profiler only briefly, reducing its received sound energy. Thus, it is unlikely that the sub-bottom profiler produces pulse levels strong enough to cause hearing impairment or other physical injuries even in an animal that is (briefly) in a position near the source.

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

Possible Effects of Multibeam Echo Sounder Signals

A Kongsberg EM122 multibeam 12 kHz echo sounder system will be operated from the *Healy* continuously during the planned study. Sounds from the multibeam are very short pulses, depending on water depth. Most of the energy in the sound pulses emitted by the multibeam is at moderately high frequencies, centered at 12 kHz. The beam is narrow (~2°) in fore-aft extent and wide (~130º) in the cross-track extent. Any given mammal at depth near the trackline would be in the main beam for only a fraction of a second. Therefore, marine mammals that encounter sound from the Kongsberg EM122 at close range are unlikely to be subjected to repeated pulses because of the narrow fore–aft width of the beam, and will receive only limited amounts of pulse energy because of the short pulses. Similarly, Kremser et al. (2005) noted that the probability of a cetacean swimming through the area of exposure when a multibeam echo sounder emits a pulse is small. The animal would have to pass the transducer at close range and be swimming at speeds similar to the vessel in order to be subjected to sound levels that could cause TTS. In 2008 and 2009 the *Louis S. St. Laurent* and the *Healy* surveyed together with a cooperative strategy similar to that proposed for 2010. The director of NOAA's Office of Ocean Exploration and Research deemed that the use of the *Healy's* multibeam would not have significant impacts on marine mammals of a direct or cumulative nature. The U.S. portions of the projects were granted a categorical exclusion from the need to prepare an Environmental Assessment.

Navy echo sounders that have been linked to avoidance reactions and stranding of cetaceans (1) generally are more powerful than the Kongsberg EM122 echo sounder, (2) have longer pulse duration, and (3) are directed close to horizontally vs. downward for the Kongsberg EM122. The area of possible influence of the bathymetric echo sounder is much smaller—a narrow band oriented in the cross-track direction below the source vessel. Marine mammals that encounter the multibeam echo sounder at close range are unlikely to be subjected to repeated pulses because of the narrow fore-aft width of the beam, and will receive only small amounts of pulse energy because of the short pulses. In assessing the possible impacts of a similar multibeam system (the 15.5 kHz Atlas Hydrosweep multibeam bathymetric echo sounder), Boebel et al. (2004) noted that the critical sound pressure level at which TTS may occur is 203.2 dB re 1 μPa (rms). The critical region included an area of 43 m in depth, 46 m wide athwartship, and 1 m fore-and-aft (Boebel et al. 2004). In the more distant parts of that (small) critical region, only slight TTS would be incurred.

Masking

Marine mammal communications will not be masked appreciably by the multibeam echo sounder signals given the low duty cycle of the echo sounder and the brief period when an individual mammal is likely to be within the echo sounder beam. Furthermore, the 12 kHz multibeam will not overlap with the predominant frequencies in baleen whale calls, further reducing any potential for masking in that group.

Behavioral Responses

Behavioral reactions of free-ranging marine mammals to military and other sonars appear to vary by species and circumstance. Observed reactions have included silencing and dispersal by sperm whales (Watkins et al. 1985), increased vocalizations and no dispersal by pilot whales (Rendell and Gordon 1999), and the previously-mentioned beachings by beaked whales. Also, Navy personnel have described observations of dolphins bow-riding adjacent to bow-mounted mid-frequency sonars during sonar transmissions. During exposure to a 21–25 kHz whale-finding sonar with a source level of 215 dB re 1 μPa·m, gray whales showed slight avoidance (~200 m) behavior (Frankel 2005).

However, all of those observations are of limited relevance to the present situation. Pulse durations from the Navy sonars were much longer than those of the multibeam echo sounders to be used during the proposed study, and a given mammal would have received many pulses from the naval sonars. During the USGS operations, the individual pulses will be very short, and a given mammal would not receive many of the downward-directed pulses as the vessel passes by.

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

We are not aware of any data on the reactions of pinnipeds to echo sounder sounds at frequencies similar to those of the multibeam echo sounder (12 kHz). Based on observed pinniped responses to other types of pulsed sounds, and the likely brevity of exposure to the multibeam echo sounder sounds, pinniped reactions to the echo sounder sounds are expected to be limited to startle or otherwise brief responses of no lasting consequence to the animals.

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

Hearing Impairment and Other Physical Effects

Given recent stranding events that have been associated with the operation of naval sonar, there is concern that mid-frequency sonar sounds can cause serious impacts to marine mammals (see above). However, the multibeam echo sounder proposed for use by USGS is quite different from sonars used for navy operations. Pulse duration of the bathymetric 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 multibeam echo sounder for much less time given the generally downward orientation of the beam and its narrow fore-aft beamwidth. (Navy sonars often use near-horizontally-directed sound.) Those factors would all reduce the sound energy received from the bathymetric echo sounder relative to that from the sonars used by the Navy.

Possible Effects of Helicopter Activities

It is anticipated that a helicopter will be deployed daily, weather permitting to conduct ice reconnaissance as well as to periodically transfer personnel between the two vessels. The helicopter will also be used to collect spot bathymetry data during operations in Canadian and international waters, outside of U.S. waters. The spot soundings will be recorded to maximize the area surveyed and the data will be collected off the ship's survey lines. A 12 kHz transducer will be slung by the helicopter and placed in the water down to a mark affixed to the tether. Data will then be logged to a laptop computer in the helicopter.

Levels and duration of sounds received underwater from a passing helicopter are a function of the type of helicopter used, orientation of the helicopter, the depth of the marine mammal, and water depth. A Canadian Coast Guard helicopter, a Messerschmitt MBB BO105, will be providing air support for this project. Helicopter sounds are detectable underwater at greater distances when the receiver is at shallow depths. Generally, sound levels received underwater decrease as the altitude of the helicopter increases (Richardson et al. 1995). Helicopter sounds are audible for much greater distances in air than in water.

Cetaceans

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

Pinnipeds

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

As mentioned in the previous section, momentary behavioral reactions "do not rise to the level of taking" (NMFS 2001). In order to limit behavioral reactions of marine mammals during ice reconnaissance and spot bathymetry work outside of U.S. waters, the helicopter will maintain a minimum altitude of 200 m (656 ft) above the sea ice except when taking off, landing or conducting spot bathymetry. Sea-ice landings are not planned at this time.

Possible Effects of Icebreaking Activities

Icebreakers produce more noise while breaking ice than ships of comparable size due, primarily, to the sounds of the propeller cavitating (Richardson et al. 1995). Multi-year ice, which is expected to be encountered in the northern and eastern areas of the proposed survey, is thicker than younger ice. Icebreakers commonly back and ram into heavy ice until losing momentum to make way. The highest noise levels usually occur while backing full astern in preparation to ram forward through the ice. Overall, the noise generated by an icebreaker pushing ice was 10-15 dB greater than the noise produced by the ship underway in open water (Richardson et al. 1995). In general, the Arctic Ocean is a noisy environment. Greening and Zakarauskas, 1993, reported ambient sound levels of up to 180 dB/ µPa2/ Hz under multi-year pack ice in the central Arctic pack ice. Little information is available about the effect to marine mammals of the increased sound levels due to icebreaking.

Cetaceans

Few studies have been conducted to evaluate the potential interference of icebreaking noise with marine mammal vocalizations. Erbe and Farmer (1998) measured masked hearing thresholds of a captive beluga whale. They reported that the recording of a Canadian Coast Guard ship, *Henry Larsen*, ramming ice in the Beaufort Sea, masked recordings of beluga vocalizations at a noise-to-signal pressure ratio of 18 dB, when the noise pressure level was eight times as high as the call pressure. Erbe and Farmer (2000) also predicted when icebreaker noise would affect beluga whales through software that combined a sound propogation model and beluga whale impact threshold models. They again used the data from the recording of the *Henry Larsen* in the Beaufort Sea and predicted that masking of beluga vocalizations could extend between 40 and 71 km near the surface. Lesage et al. (1999) report that beluga whales changed their call type and call frequency when exposed to boat noise. It is possible that the whales adapt to the ambient noise levels and are able to communicate despite the sound. Given the documented reaction of belugas to ships and icebreakers (see below) it is highly unlikely that beluga whales would remain in the proximity of vessels where their vocalizations would be masked.

Beluga whales have been documented swimming rapidly away from ships and icebreakers in the Canadian high arctic when a ship approaches to within 35-50 km, and they may travel up to 80 km from the vessel's track (Richardson et al. 1995). It is expected that belugas avoid icebreakers as soon as they detect the ships (Cosens and Dueck 1993). Although, the reaction of beluga whales to ships vary greatly and some animals may become habituated to higher levels of ambient noise (Erbe and Farmer 2000).

There is little information about the effects of icebreaking ships on baleen whales. Migrating bowhead whales appeared to avoid an area around a drillsite by >25 km where an icebreaker was working in the Beaufort Sea. There was intensive icebreaking daily in support of the drilling activities (Brewer et al. 1993). Migrating bowheads also avoided a nearby drillsite at the same time of year where little icebreaking was being conducted (LGL and Greeneridge 1987). It is unclear as to whether the drilling activies, icebreaking operations, or the ice itself might have been the cause for the whales' diversion.

Pinnipeds

Brueggeman et al. (1992) reported on the reactions of seals to an icebreaker during activities at two prospects in the Chukchi Sea. Reactions of seals to the icebreakers varied between the two prospects. Most (67%) seals did not react to the icebreaker at either prospect. Reaction at one prospect was greatest during icebreaking activity followed by general vessel activity (running/maneuvering/jogging) and was lowest while the vessel was at anchor or drifting. Frequency of reaction was greatest for animals within 0.23 km of the vessel and lowest for animals beyond 0.93 km. At the second prospect however, seal reaction was lowest during icebreaking activity with higher and similar levels of response during general (non-icebreaking) vessel operations and when the vessel was at anchor or drifting. The frequency of seal reaction generally declined with increasing distance from the vessel except during general vessel activity where it remained consistently high to about 0.46 km from the vessel before declining.

Similarly, Kanik et al. (1980) found that ringed seals and harp seals often dove into the water when an icebreaker was breaking ice within 1 km of the animals. Most seals remained on the ice when the ship was breaking ice 1-2 km away.

Numbers of Marine Mammals that Might be "Taken by Harassment"

All anticipated takes would be "takes by harassment", as described in § V, involving temporary changes in behavior. The mitigation measures to be applied will minimize the possibility of injurious takes. (However, as noted earlier and in Appendix D, there is no specific information demonstrating that injurious "takes" would occur even in the absence of the planned mitigation measures.) The sections below describe methods used to estimate "take by harassment" and present estimates of the numbers of marine mammals that might be affected during the proposed seismic study in the Arctic Ocean. The estimates are based on data obtained during marine mammal surveys in and near the Arctic Ocean by Stirling et al. (1982), Kingsley (1986), Moore et al. (2000b), Haley and Ireland (2006), Haley (2006), GSC unpubl. data (2008) and Mosher et al. (2009), Bowhead Whale Aerial Survey Program (BWASP), 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.

Detectability bias, quantified in part by *f*(0), is associated with diminishing sightability with increasing lateral distance from the trackline. Availability bias (*g*[0]) refers to the fact that there is

<100% probability of sighting an animal that is present along the survey trackline. Some sources of densities used below included these correction factors in their reported densities. In other cases the best available correction factors were applied to reported results when they had not been included in the reported data (e.g. Moore et al. 2000b). Adjustments to reported population or density estimates were made on a case by case basis to take into account differences between the source data and the general information on the distribution and abundance of the species in the project area.

Although several systematic surveys of marine mammals have been conducted in the southern Beaufort Sea, few data (systematic or otherwise) are available on the distribution and numbers of marine mammals in the northern Beaufort Sea or offshore water of the Arctic Ocean. The main sources of distributional and numerical data used in deriving the estimates are described in the next subsection. Both "maximum estimates" as well as "best estimates" of marine mammal densities (Table 5) and the numbers of marine mammals potentially exposed to underwater sound (Table 6) were calculated as described below. The best (or average) estimate is based on available distribution and abundance data and represents the most likely number of animals that may be encountered during the survey, assuming no avoidance of the airguns or vessel. The maximum estimate is either the highest estimate from applicable distribution and abundance data or the average estimate increase by a multiplier intended to produce a very conservative (over) estimate of the number of animals that may be present in the survey area. There is some uncertainty about how representative the available 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.

We have calculated exposures to marine mammals within U.S. waters only. After the *Louis S. St. Laurent*, a Canadian icebreaker, exits U.S. waters, their activities no longer fall under the jurisdiction of the United States or the MMPA.

The following estimates are based on a consideration of the number of marine mammals that might be disturbed appreciably over the ~806 line kilometers of seismic surveys within U.S. waters across the Arctic Ocean. An assumed total of 1007.5 km of trackline includes a 25% allowance over and above the planned ~806 km to allow for turns, lines that might have to be repeated because of poor data quality, or for minor changes to the survey design.

The anticipated radii of influence of the lower energy sound sources including Chirp echo sounder (on the *Louis S. St. Laurent*) and bathymetric echo sounder (on the *Healy*) are less than that for the airgun configuration. It is assumed that during simultaneous operations of the airgun array and sounder, any marine mammals close enough to be affected by the sounder would already be affected by the airguns. However, whether or not the airguns are operating simultaneously with the echo sounder, marine mammals are expected to exhibit no more than short-term and inconsequential responses to the sounder given its characteristics (e.g., narrow downward-directed beam) and other considerations described in § I and in § VII above. Similar responses are expected from marine mammals exposed to the *Healy's* bathymetric profiler. Such reactions are not considered to constitute "taking" as defined by NMFS (NMFS 2001). Therefore, no additional allowance is included for animals that might be exposed to sound sources other than the airguns.

Marine Mammal Density Estimates

Numbers of marine mammals that might be present and potentially disturbed are estimated below based on available data about mammal distribution and densities in the area. "Take by harassment" is calculated by multiplying the expected densities of marine mammals likely to occur in the survey area by the area of water potentially ensonified to sound levels ≥160 dB re 1 µPa (rms). This section provides descriptions of the estimated densities of marine mammals that may occur in the survey area. The area of water that may be ensonified to the indicated sound level is described further below in the section Potential Number of "Takes by Harassment". There is no evidence that avoidance at received sound levels ≥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).

Some surveys of marine mammals have been conducted near the southern end of the proposed project area, but few data are available on the species and abundance of marine mammals in the northern Beaufort Sea and the Arctic Ocean. No published densities of marine mammals are available for this region, although vessel-based surveys through the general area in 2005, 2006, 2008 and 2009 encountered few marine mammals. A total of two polar bears, 36 seals, and a single beluga whale sighting(s) were recorded along ~2299 km of monitored trackline between 71°N and 74°N (Haley and Ireland 2006, Haley 2006, GSC unpubl. data 2008, Mosher et al. 2009).

Given that the survey lines within U.S. waters extend from latitudes 71° to 74°N, it is likely that seismic operations will be conducted in both open-water and sea-ice conditions. Because densities of marine mammals often differ between open-water and pack-ice areas, the likely extent of the pack ice at the time of the survey was estimated. Images of average monthly sea ice concentration for August from 2005 through 2009, available from the National Snow and Ice Data Center (NSIDC), were used to identify 74°N latitude as a reasonable ice-edge boundary applicable to the proposed study period and location. Based on these satellite data, the majority of the survey in U.S. waters will be conducted in open water and unconsolidated pack ice, in the southern latitudes of the survey area. This region will include the ice margin where the highest densities of cetaceans and pinnipeds are likely to be encountered. The proposed survey lines within U.S. waters reach ~74°10'N, extending within the estimated ice-edge boundary for August 2010 by ~19 km (~10 n.mi.). This comprises less than 3% of the total trackline within U.S. waters. We have divided the survey effort between the two habitat zones of open water and ice margin based on the 2005 – 2009 NSIDC satellite data described above and the planned location of the tracklines. NSIDC data from 2005-2009 suggests little ice will be present south of 74°N, although data from the 2009 cruise (Moser et al. 2009) shows that inter-annual variability could result in a greater amount of ice being encountered than expected. As a conservative measure, we estimated that, within U.S. waters, 80% of the survey tracklines will occur in open water and 20% of the tracklines will occur within the ice margin.

The NSIDC (2009) reported that more Arctic sea ice cover in 2009 remained after the summer than in the record-setting low years of 2007 and 2008. We expect that sea ice density and extent in 2010 will be closer to the density and extent of sea ice in 2009 rather than the record-setting low years of 2007 and 2008. All animals observed during the 2009 survey (Mosher et al. 2009) were north of the proposed seismic survey area, i.e. north of 74°N.

Cetaceans

Average and maximum densities for each cetacean species or species group reported to occur in U.S. waters of the Arctic Ocean, within the study area, are presented below. Densities were calculated based on the sightings and effort data from available survey reports. No cetaceans were observed during surveys near the proposed study area in August/September 2005 (Haley and Ireland 2006), August 2006 (Haley 2006), August/September 2008 (GSC unpubl. data 2008) or August/September 2009 (Mosher et al. 2009).

Seasonal (summer and fall) differences in cetacean densities along the north coast of Alaska have been documented by Moore et al. (2000b). The proposed survey will be conducted in U.S. waters from ~6–12 August and is considered to occur during the summer season.

The summer ***beluga*** density (Table 5) was based on 41 sightings along 9022 km of on-transect effort that occurred over water >2000 m during the summer in the Beaufort Sea (Moore et al. 2000b; Table 2). A mean group size of 2.8 (CV=1.0) derived from BWASP data of August beluga sightings in the Beaufort Sea in water depths >2000 m was used in the density calculation. An *f*(0) value of 2.326 from Innes et al (1996) and a *g*(0) value of 0.419 from Innes et al. (1996) and Harwood et al. (1996) were also used in the density computation. The CV associated with group size was used to select an inflation factor of 2 to estimate the maximum density that may occur in the proposed study area within U.S. waters. Most Moore et al. (2000b) sightings were south of the proposed seismic survey. However, Moore et al. (2000b) found that beluga whales were associated with both light (1 – 10%) and heavy (70 – 100%) ice cover. Five of 23 beluga whales that Suydam et al. (2005) tagged in Kasegaluk Lagoon (northeast Chukchi Sea) travelled to 79 - 80°N into the pack ice and within the region of the proposed survey. These and other tagged whales moved into areas as far as 1100 km (594 n.mi.) offshore between Barrow and the Mackenzie River delta, spending time in water with 90% ice coverage. Therefore, we applied the observed density calculated from the Moore et al. (2000b) sightings as the average density for both "open water" and "ice margin" habitats. Because no beluga whales were sighted during recent surveys in the proposed survey area (Harwood et al. 2005; Haley and Ireland 2006; Haley 2006; GSC unpubl. data 2008; and Mosher et al. 2009) the densities in Table 5 are likely higher than densities likely to be encountered.

By the time the survey begins in early August, most ***bowhead*** *whales* have typically traveled east of the proposed project area to summer in the eastern Beaufort Sea and Amundsen Gulf. Industry aerial surveys of the continental shelf near Camden Bay in 2008 recorded eastward migrating bowhead whales until 12 July (Lyons and Christie 2009). No bowhead sightings were recorded again despite continued flights until 19 August. A summer bowhead whale density was derived from 9022 km of summer (July/August) aerial survey effort reported by Moore et al. (2000b) in the Alaskan Beaufort Sea during which six sightings of bowhead whales were documented in water >2000 m deep. A mean group size for bowhead whale sightings in September, in waters >2000 m deep, was calculated to be 1.14 (CV=0.4) from BWASP data. An *f*(0) value of 2.33 and a *g*(0) value of 0.073, both from Thomas et al. (2002) were used to estimate a summer density for bowhead whales of 0.0122 whales/ km^2. This density falls within the range of densities, i.e. 0.0099 – 0.0717 whales/ km^2, reported by Lyons and Christie (2009) based on data from three July 2008 surveys.

Treacy et al. (2006) reported that in years of heavy ice conditions, bowhead whales occur farther offshore than in years of light to moderate ice. NSIDC (2009) reported that September 2009 had the third lowest sea ice extent since the start of their satellite records in 1979. The extent of sea ice at the end of the 2009 Arctic summer, however, was greater than in 2007 or 2008. We do not expect 2010 to be a heavy ice year during which bowhead whales might occur farther offshore in the area of the proposed survey. During the lowest ice-cover year on record (2007), BWASP reported no bowhead whale sightings in the >2000 m depth waters far offshore. Because few bowhead whales have been documented in the deep offshore waters of the proposed survey area, half of the bowhead whale density estimate from Moore et al. (2000b) was applied as the average density (0.0061 whales/km^2; Table 5). The CV of group size and standard errors reported in Thomas et al (2002) for *f*(0) and *g*(0) correction factors suggest that an inflation factor of 2 is appropriate for estimating the maximum density from the average density. NSIDC did not forecast that 2010 would be a heavy ice year and we anticipate that bowheads will remain relatively close to shore, and in areas of light ice coverage. Therefore, we have applied the same density for bowheads to the open-water and ice-margin categories. Bowhead whales were not sighted during recent surveys in the Arctic Ocean (Haley and Ireland 2006; Haley 2006; GSC unpubl. data 2008; Mosher et al. 2009), suggesting that the bowhead whale densities shown in Table 5 are likely higher than actual densities in the survey area.

For ***other cetacean species*** that may be encountered in the Beaufort Sea, densities are likely to be very low in the summer when the survey is scheduled. Fin and humpback whales are unlikely to occur in the Beaufort Sea. No gray whales were observed in the Beaufort Sea by Moore et al. (2000b) during summer aerial surveys in water >2000 m. Gray whales were not recorded in water >2000 m by the BWASP during August in 29 years of survey operation. Harbor porpoises are not expected to be present in large numbers in the Beaufort Sea during the fall although small numbers may be encountered during the summer. Neither gray whales nor harbour porpoises are likely to occur in the far-offshore waters of the proposed survey area (Table 5). Narwhals are not expected to be encountered within the survey area although a few individuals could be present if ice is nearby. Because these species occur so infrequently in the Beaufort Sea, little to no data are available for the calculation of densities. Minimal cetacean densities have therefore been assigned to these three species for calculation purpose and to allow for chance encounters (Table 5). Those densities include “0” for the average and 0.0001 individuals/km^2 for the maximum.

Seals

Extensive surveys of ringed and bearded seals have been conducted in the Beaufort Sea, but most surveys were conducted over the landfast ice during aerial surveys, and few seal surveys have occurred in open water or in the pack ice. Kingsley (1986) conducted ***ringed seal*** surveys of the offshore pack ice in the central and eastern Beaufort Sea during late spring (late June). These surveys provide the most relevant information on densities of ringed seals in the ice margin zone of the Beaufort Sea. The density estimate in Kingsley (1986) was used as the average density of ringed seals that may be encountered in the ice-margin area of the proposed survey (Table 5). The average density was multiplied by 4 to estimate maximum density, as was done for all seal species likely to occur within the survey area. Ringed seals are closely associated with sea ice therefore the ice-margin densities were multiplied by a factor of 0.75 to estimate a summer open-water ringed-seal density for locations with water depth >2000 m.

TABLE 5. Expected summer densities of marine mammals, in U.S. waters, offshore in the Beaufort Sea and Arctic Ocean. This area is expected to be mostly open water and may extend into the ice margin. Densities are corrected for *f*(0) and *g*(0) biases. Species listed as endangered are in italics.

	Open Water		Ice Margin	
Species	**Average Density (# / km^2)**	**Maximum Density (# / km^2)**	**Average Density (# / km^2)**	**Maximum Density (# / km^2)**
Odontocetes				
Beluga	0.0354	0.0709	0.0354	0.0709
Narwhal	0.0000	0.0001	0.0000	0.0002
Delphinidae				
Killer whale	0.0000	0.0001	0.0000	0.0001
Phocoenidae				
Harbor porpoise	0.0000	0.0001	0.0000	0.0001
Mysticetes				
Bowhead whale	0.0061	0.0122	0.0061	0.0122
Gray whale	0.0000	0.0001	0.0000	0.0001
Minke whale	0.0000	0.0001	0.0000	0.0001
Fin whale	0.0000	0.0001	0.0000	0.0001
Humpback whale	0.0000	0.0001	0.0000	0.0001
Pinnipeds				
Bearded seal	0.0096	0.0384	0.0128	0.0512
Spotted seal	0.0001	0.0004	0.0001	0.0004
Ringed seal	0.1883	0.7530	0.2510	1.0040

Densities of ***bearded seals*** were estimated by multiplying the ringed seal densities by 0.051 based on the proportion of bearded seals to ringed seals reported in Stirling et al. (1982; Table 6-3). Because bearded seals are associated with the pack ice edge and shallow water, their estimated summer ice-margin density was also multiplied by a factor of 0.75 for the open-water density estimate. Minimal values were used to estimate ***spotted seal*** densities because they are uncommon offshore in the Beaufort Sea and are not likely to be encountered.

Potential Number of "Takes by Harassment"

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

Numbers of marine mammals that might be present and potentially disturbed are estimated below based on available data about mammal distribution and densities in the two different habitats during the summer as described above.

The number of individuals of each species potentially exposed to received levels ≥160 dB re 1 μPa (rms) was estimated by multiplying

- the anticipated area to be ensonified to the specified sound level in both open water and the ice margin, by
- the expected species density

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

Estimated Area Exposed to ≥160 dB rms

The area of water potentially exposed to received levels ≥160 dB by the proposed operations was calculated by multiplying the planned trackline distance within U.S. waters by the cross-track distance of the sound propagation. The airgun array of two 500 in^3 and one 150 in^3 G-guns that will be used for the proposed 2010 survey within U.S. waters was measured during a 2009 project in the Arctic Ocean. The propagation experiment took place at 74°50.4'N; 156°34.31'W, in 3863 m of water. The location was near to the northern end of the two proposed survey lines in U.S. waters. We expect the sound propagation by the airgun array in the planned 2010 survey will be the same as that measured in 2009, because of the similar water depths and relative locations of the test site and proposed survey area. The ≥160 dB rms sound level radius was estimated to be ~2500 m (1.3 n.mi.) based on modeling of the 0-peak energy of the airgun array (Roth and Schmidt 2010). The 0-peak values were corrected to rms by subtracting 10 dB.

Closely spaced survey lines and large cross-track distances of the ≥160 dB radii can result in repeated exposure of the same area of water. Excessive amounts of repeated exposure can lead to overestimation of the number of animals potentially exposed through double counting. The trackline for the proposed USGS survey in U.S. water, however, covers a large geographic area without adjacent tracklines and the potential for multiple or repeated exposure is unlikely to be a concern.

The USGS 2010 geophysical survey is planned to occur ~108 km offshore, along ~806 km (435 n.mi.) of survey lines in U.S. waters, during the first half of August exposing a total of ~4109 km^2 of water to sound levels ≥160 dB rms. We included an additional 25% allowance over and above the planned tracklines within U.S. waters to allow for turns, lines that might have to be repeated because of poor data quality, or for minor changes to the survey design. The resulting estimate of 5136.5 km^2 was used to estimate the numbers of marine mammals exposed to underwater sound levels ≥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 in the proposed survey area within U.S. waters are presented in Table 6. For the common species, the requested numbers are calculated as described above and based on the average densities from the data reported in the different studies mentioned above. For less common species, estimates were set to minimal values to allow for chance encounters. Discussion of the number of potential exposures is summarized by species in the following subsections.

Cetaceans

Based on density estimates and the area ensonified, one endangered cetacean species (bowhead whale) is expected to be exposed to received sound levels ≥160 dB unless bowheads avoid the survey vessel before the received levels reach 160 dB. Migrating bowheads are likely to do so, though many of the bowheads engaged in other activities, particularly feeding and socializing may not. Our estimate of the number of bowhead whales potentially exposed to sound levels ≥160 dB in the portion of the survey area in U.S. waters is between 31 and 63 (Table 6). Other endangered cetacean species that may be encountered in the area are fin and humpback whales, both are unlikely to be exposed given their minimal density in the area.

The only other cetacean species likely to occur in the proposed survey area is beluga whale. Average (best) and maximum estimates of the number of exposures of belugas to sound levels ≥160 dB rms are 182 and 364, respectively. Estimates for other cetacean species are minimal (Table 6).

Pinnipeds

Ringed seal is the most widespread and abundant pinniped in ice-covered arctic waters, and there is a great deal of annual variation in abundance 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 re 1 μPa (rms) during the proposed marine survey. The average (best) and maximum number of exposures of ringed seals to sound levels ≥160 dB rms were estimated to be 1031 and 4126, respectively.

Two additional pinniped species (other than the Pacific walrus) are likely to occur in the proposed project area. The average and maximum numbers of exposures of bearded seals to sound levels ≥160 dB rms were estimated to be 53 and 210, respectively. Average and maximum number of exposures of spotted seal were estimated to be 1 and 2, respectively. The ribbon seal is unlikely to be encountered in the survey area, but a chance encounter could occur.

Conclusions

Cetaceans

Bowhead whales are considered by NMFS to be disturbed after exposure to underwater sound levels ≥160 dB. The relatively small airgun array proposed for use in this survey limits the size of the 160 dB zone around the vessel and will result in few bowhead whale exposures to underwater sound levels sufficient to reach the disturbance criterion as defined by NMFS.

Odontocete reactions to seismic energy pulses are usually assumed to be limited to lesser distances from the airgun(s) than are those of mysticetes, probably in part because odontocete low-frequency hearing is assumed to be less sensitive than that of mysticetes. However, at least when in the Canadian Beaufort Sea in summer, belugas appear to be fairly responsive to seismic energy, with few being sighted within 10–20 km of seismic vessels during aerial surveys (Miller et al. 2005). Belugas will likely occur in small numbers in the project area within U.S. waters during the survey period. Most belugas will likely avoid the vicinity of the survey activities and few will likely be affected.

TABLE 6. Estimates of the numbers of marine mammals potentially exposed to received sound levels ≥160 dB during USGS's proposed seismic program in U.S. waters in the northern Beaufort Sea and Arctic Ocean, ~6 - 12 August, 2010. Species in italics are listed under the U.S. ESA as endangered.

	Number of Exposures to Sound Levels ?160 dB					
	Open Water		**Ice Margin**		**Total**	
Species	**Average**	**Maximum**	**Average**	**Maximum**	**Average**	**Maximum**
Odontocetes						
Monodontidae						
Beluga	146	291	36	73	182	364
Narwhal	0	1	0	1	0	2
Delphinidae						
Killer whale	0	0	0	0	0	1
Phocoenidae						
Harbor porpoise	0	0	0	0	0	1
Mysticetes						
Bowhead whale	25	50	6	13	31	63
Gray whale	0	0	0	0	0	1
Minke whale	0	0	0	0	0	0
Fin whale	0	0	0	0	0	0
Humpback whale	0	0	0	0	0	0
Total Cetaceans	171	344	43	87	213	430
Pinnipeds						
Bearded seal	39	158	13	53	53	210
Spotted seal	0	2	0	0	1	2
Ringed seal	774	3094	258	1031	1031	4126
Total Pinnipeds	813	3254	271	1084	1085	4338

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". Furthermore, the estimated numbers of animals potentially exposed to sound levels sufficient to cause appreciable disturbance are very low percentages of the population sizes in the Bering–Chukchi–Beaufort seas, as described below.

Based on the ≥160 dB disturbance criterion, the *best (average) estimates* of the numbers of cetacean *exposures* to sounds ≥160 dB re 1 µPa (rms) represent <1% of the populations of each species in the Chukchi Sea and adjacent waters (*cf.* Table 6-1). For species listed as "*Endangered*" under the ESA, our estimates suggest it is unlikely that fin whales or humpback whales will be exposed to received levels ≥160 dB rms, but that ~31 bowheads may be exposed at this level. The latter is <1% of the Bering–Chukchi–Beaufort population of >14,247 assuming 3.4% annual population growth from the 2001 estimate of >10,545 animals (Zeh and Punt 2005).

Some monodontids may be exposed to sounds produced by the airgun arrays during the proposed survey, and the numbers potentially affected are small relative to the population sizes (Table 6). The best estimate of the number of belugas that might be exposed to ≥160 dB (182) represents <1% of their population.

The many reported cases of apparent tolerance by cetaceans of seismic exploration, vessel traffic, and some other human activities show that co-existence is possible. Mitigation measures such as controlled vessel speed, dedicated marine mammal observers, non-pursuit, shut downs or power downs when marine mammals are seen within defined ranges will further reduce short-term reactions and minimize any effects on hearing sensitivity. In all cases, the effects are expected to be short-term, with no lasting biological consequence.

Subsistence issues are addressed below in section VIII. USGS has adopted a spatial and temporal operational strategy that, when combined with its community outreach and engagement program, will provide effective protection to the bowhead migration and subsistence hunt.

Pinnipeds

Several pinniped species may be encountered in the study area, but ringed seal is by far the most abundant marine mammal species in the survey area. The best (average) estimates of the numbers of individuals seals exposed to airgun sounds at received levels ≥160 dB re 1 µPa (rms) during the marine survey are as follows: ringed seals (1031), bearded seals (53), and spotted seals (1), representing <1% of the Bearing–Chukchi–Beaufort populations for each species. It is probable that only a small percentage of the pinnipeds exposed to sound level≥160 dB would actually be disturbed. The short -term exposures of pinnipeds to airgun sounds are not expected to result in any long-term negative consequences for the individuals or their populations.

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, belugas, and walruses 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 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) which extends to 2012 (NMFS 2008b). The AEWC allots the number of bowhead whales that each whaling community may harvest annually during five-year periods (USDI/BLM 2005; NMFS 2008).

The community of Barrow hunts bowhead whales in both the spring and fall during the whales' seasonal migrations along the coast (Fig. 2). Often the bulk of the Barrow bowhead harvest is taken during the spring hunt. However, with larger quotas in recent years, it is common for a substantial fraction of the annual Barrow quota to remain available for the fall hunt (Table 7). The communities of Nuiqsut and 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).

Table 7. 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. Cross Isl. (Nuiqsut) and Kaktovik landings are in autumn.

Year	Point Hope	Wainwright	Barrow	Cross Island	Kaktovik
1993	2	5	23 (7)	3	3
1994	5	4	16 (1)	0	3
1995	1	5	19 (11)	4	4
1996	3	3	24 (19)	2	1
1997	4	3	30 (21)	3	4
1998	3	3	25 (16)	4	3
1999	2	5	24 (6)	3	3
2000	3	5	18 (13)	4	3
2001	4	6	27 (7)	3	4
2002	0	1	22 (17)	4	3
2003	4	5	16 (6)	4	3
2004	3	4	21 (14)	3	3
2005	7	4	29 (13)	1	3
2006	0	2	22 (19)	4	3
2007	3	4	20 (7)	3	3
2008	2	2	21(12)	4	3

Sources:USDI/BLM and references therein; Burns et al. (1993); Koski et al. (2005); Suydam et al. 2004, 2005, 2006, 2007, 2008, 2009.

The spring hunt at Barrow occurs after leads open due to the deterioration of pack ice; the spring hunt typically occurs from early April until the first week of June. The location of the fall subsistence hunt depends on ice conditions and (in some years) industrial activities that influence the bowheads as they move west (Brower 1996). In the fall, subsistence hunters use aluminum or fiberglass boats with outboards. Hunters prefer to take bowheads close to shore to avoid a long tow during which the meat can spoil, but Braund and Moorehead (1995) report that crews may (rarely) pursue whales as far as 80 km. The 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 has been discussed with representatives of those concerned with the subsistence bowhead hunt, most notably the AEWC, the Barrow Whaling Captains' Association, and the North Slope Borough (NSB) Department of Wildlife Management. The timing of the proposed geophysical survey in early – mid-August will affect neither the spring nor the fall bowhead hunt. The *Healy* is planning to change crew after completion of the geophysical survey through Barrow via helicopter or boat. That crew change is scheduled ~4–5 September, well before the fall bowhead whaling which typically begins late September or early October. All of the proposed geophysical activities will occur offshore between 71º and 84ºN latitude well north of Beaufort Sea whaling activities.

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 1997; Alaska Beluga Whale Committee 2002 *in* USDI/BLM 2005). The proposed geophysical survey is unlikely to overlap with the beluga harvest, and the survey initiates well outside the area where impacts to beluga hunting by Barrow villagers could occur.

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 harvest by the community of Barrow from the 1960s through much of the 1980s has been estimated as 394 (Table 8). More recently Bacon et al. (2009) estimated that 586, 287, and 413 ringed seals were harvested by villagers at Barrow in 2000, 2001, and 2003, respectively. Although ringed seals are available year-round, the seismic survey will not occur during the primary period when these seals are typically harvested. Also, 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.

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

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

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

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

The ***spotted seal*** subsistence hunt peaks in July and August, at least in 1987 to 1990, but involves few animals. Spotted seals typically migrate south by October to overwinter in the Bering Sea. Admiralty Bay, <60 km to the east of Barrow, is a location where spotted seals are harvested. Spotted seals are also occasionally hunted in the area off Point Barrow and along the barrier islands of Elson Lagoon to the east (USDI/BLM 2005). The average annual spotted seal harvest by the community of Barrow from 1987-1990 was one (Braund et al. 1993; Table 7). More recently however, Bacon et al. (2009) estimated that 32, 7, and 12 spotted seals were harvested by villagers at Barrow in 2000, 2001, and 2003, respectively. Spotted seals become less abundant at Nuiqsut and Kaktovik and few if any spotted seal are harvested at these villages. The seismic survey will commence at least 115 km offshore from the preferred nearshore harvest area of these seals.

Bearded seals, although not favored for their meat, are important to subsistence activities in Barrow because of their skins. Six to nine bearded seal hides are used by whalers to cover each of the skin-covered boats traditionally used for spring whaling. Because of their valuable hides and large size, bearded seals are specifically sought. Bearded seals are harvested during the summer months in the Beaufort Sea (USDI/BLM 2005). The animals inhabit the environment around the ice floes in the drifting ice pack, so hunting usually occurs from boats in the drift ice. Braund et al. (1993) estimated that 174 bearded seals were harvested annually at Barrow from 1987-1990 (Table 8). More recently Bacon et al. (2009) estimated that 728, 327, and 776 bearded seals were harvested by villagers at Barrow in 2000, 2001, and 2003, respectively. Braund et al. (1993) mapped the majority of bearded seal harvest sites from 1987 to 1990 as being within ~24 km of Point Barrow, well inshore of the proposed survey which is to start ~115 km offshore and terminate >200 km offshore. The average annual take of bearded seals by the Barrow community from 1987 to 1990 was 174 (Table 8).

Subsistence Fishing

Subsistence fishing is conducted through the year, but most actively during the summer and fall months. Fishing is often done as 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 the proposed survey will be conducted (MMS 1996).

Seismic surveys can, at times, cause changes in the catchability of fish (Appendix E). In the unlikely event that subsistence fishing (or hunting) is occurring within 5 km (3 mi) of the *Louis S. St. Laurent*'s trackline, or within other situations where potential impacts could occur, the airgun operations will be suspended until the vessel is >5 km away and otherwise not interfering with subsistence activities. The location of the proposed geophysical survey however, is well offshore and far from subsistence fishing activities.

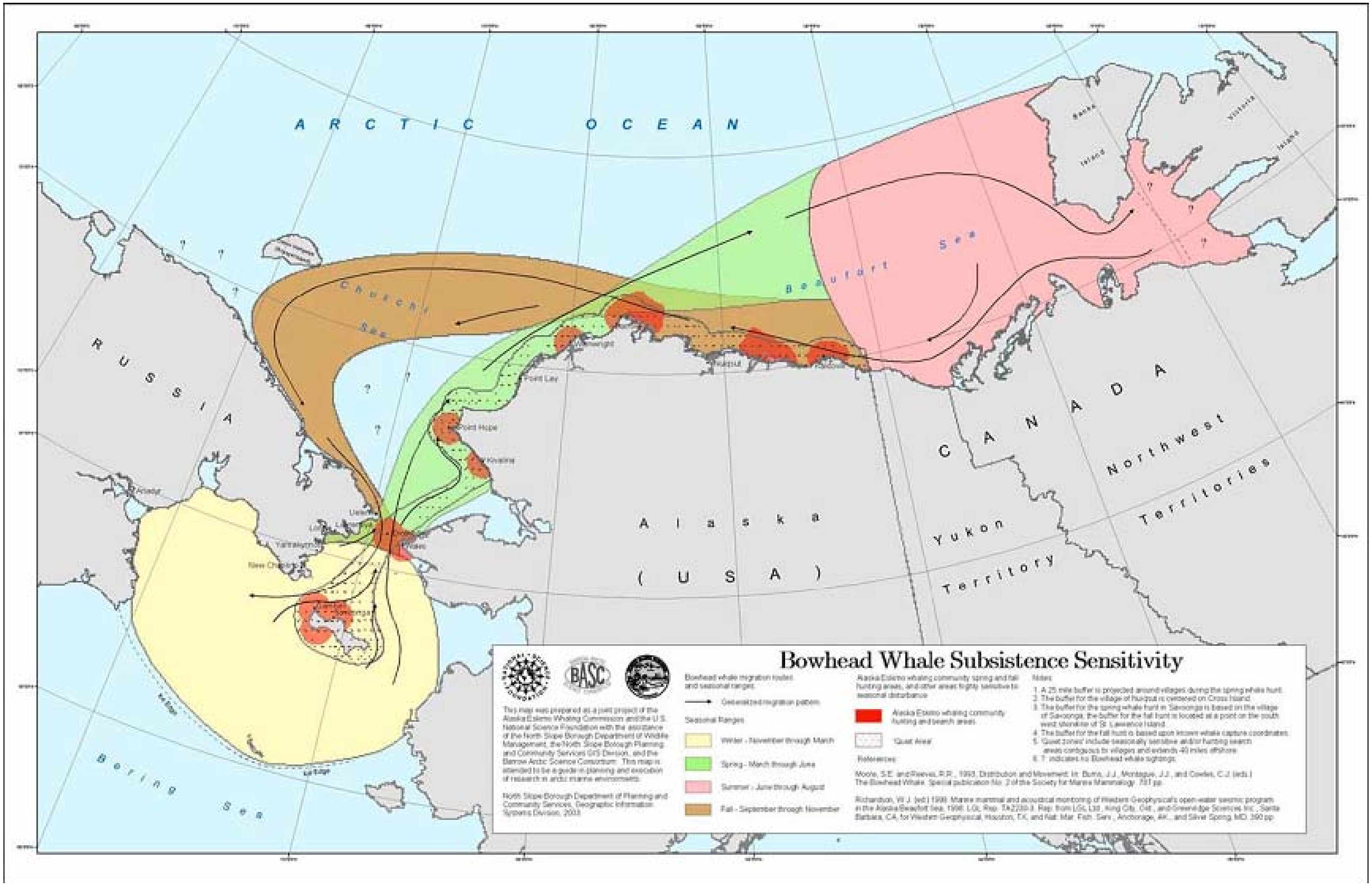

FIGURE 2. Bowhead subsistence harvest areas indicating the extent offshore where subsistence hunting is conducted (NSF 2004).

IX. ANTICIPATED IMPACT ON HABITAT

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

The proposed seismic survey will not result in any permanent impact on habitats used by marine mammals, or to the food sources they utilize. 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. Although there is the potential for the destruction of ringed seal lairs or polar bear dens due to icebreaking, these animals will not be using lairs or dens at the time of the planned survey.

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 very limited.

In water, acute injury and death of organisms exposed to seismic energy depends primarily on two features of the sound source: (1) the received peak pressure, and (2) the time required for the pressure to rise and decay (Hubbs and Rechnitzer 1952; 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 and well away from the nearshore waters where most subsistence fishing activities occur.

The only designated Essential Fish Habitiat (EFH) species that may occur in the area of the project during the seismic survey are salmon (adult), and their occurrence in waters 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 (Appendix E). 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.

Studies have been conducted on the effects of seismic activities on fish larvae and a few other invertebrate animals. Generally, seismic was found to only have potential harmful effects to larvae and invertebrates that are in direct proximity (a few meters) of an active airgun array (Appendix E, Appendix F). The proposed Arctic Sea seismic program for 2010 is predicted to have negligible to low physical effects on the various life stages of fish and invertebrates. Therefore, physical effects of the proposed program on the fish and invertebrates would not be significant

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

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

The proposed airgun operations will not result in any permanent impact on habitats used by marine mammals, or to the food sources they use. The main impact issue associated with the proposed activities will be temporarily elevated noise levels and the associated direct effects on marine mammals, as discussed above, as well as the potential effects of icebreaking. The potential effects of icebreaking include locally altered ice conditions which may temporarily alter the haul-out pattern of seals in the immediate vicinity of the vessel. The destruction of ringed seal lairs or polar bear dens is not expected to be a concern at this time of year.

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

Some mysticetes, including bowhead whales, feed on concentrations of zooplankton. Some feeding bowhead whales may occur in the Alaskan Beaufort Sea in July and August, and others feed intermittently during their westward migration in September and October (Richardson and Thomson [eds.] 2002; Lowry et al. 2004; Lyons et al. 2009; Christi et al. 2009). 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.

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

XI. MITIGATION MEASURES

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

For the proposed seismic survey in the Arctic Ocean, USGS will deploy an airgun array of three G-guns. The source will be small in size and source level, relative to airgun arrays typically used for industry seismic surveys. However, the airguns comprising the array will be clustered with only limited horizontal separation (see Appendix B), so the arrays will be less directional than is typically the case with larger airgun arrays. This will result in less downward directivity than is often present during seismic surveys, and more horizontal propagation of sound.

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

- airgun operations will be limited to offshore waters, far from areas where there is subsistence hunting or fishing, and in waters where marine mammal densities are generally low;
- in deep offshore waters (where the survey will occur), sound from the airguns is expected to attenuate relatively rapidly as compared with attenuation in shallower waters;

In addition to these mitigation measures that are built into the general project design, several specific mitigation measures will be implemented to avoid or minimize effects on marine mammals encountered along the tracklines. These include ramping up the airguns at the beginning of operations, and power-downs or shutdowns when marine mammals are detected within specified distances from the source. The GSC has written a Categorical Declaration (Appendix C) stating that,

> While in U.S. waters (i.e. the U.S. 200-mile Exclusive Economic Zone), the GSC operators will comply with any and all environmental mitigation measures required by the U.S. National Marine Fisheries Service (NMFS) and/or the U.S. Fish and Wildlife Service (FWS.)

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

Vessel-based observers will watch for marine mammals near the airgun(s) when they are in use. Mitigation and monitoring measures proposed to be implemented for the seismic survey have been developed and refined in cooperation with NMFS during previous seismic studies in the Arctic and described in associated EAs, IHA Applications, and IHAs. The mitigation and monitoring measures described herein represent a combination of the procedures required by past IHAs for Arctic projects.

Some cetacean species (such as bowhead whale) may be feeding or migrating in the Beaufort Sea during August and September. However, most of the proposed geophysical activities will occur north of the main migration corridor and the number of individual animals expected to closely approach the vicinity of the proposed activity will be small in relation to regional population sizes. With the proposed monitoring, ramp-up, power-down, and shut-down provisions (see below), any effects on individuals are expected to be limited to behavioral disturbance. The expected impacts on marine mammals are expected to be negligible.

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

Marine Mammal Monitoring

Vessel-based observers will monitor for marine mammals near the seismic source vessel during all daytime airgun operations and during any nighttime start ups of the airguns. The survey area within U.S. waters is located within high latitudes (~72°N–74°N) and the project will take place during the summer when little darkness will be encountered (Table 9). Some periods of darkness will be encountered towards the end of the survey when there will be several hours between sunset and sunrise.

The protected species observers' (PSO's) observations will provide the real-time data needed to implement the key mitigation measures. Airgun operations will be powered down or (if necessary) shut down when marine mammals are observed within, or about to enter, designated safety radii (see below) where there is a possibility of effects on hearing or other physical effects. Vessel-based MMOs will also watch for marine mammals near the seismic vessel for at least 30 min prior to the planned start of airgun operations after an extended shut down of the airgun. When feasible, observations will also be made during daytime periods without seismic operations (e.g., during transits).

TABLE 9. The daylight times and periods within the project area from beginning (7 Aug.) to end (3 Sep.) of all planned survey activities within latitudes of the planned survey within U.S. waters. Time is AKDT.

	72°N		74°N	
	07-Aug	03-Sep	07-Aug	03-Sep
Sunrise	09:29	12:14	-	12:00
Sunset	06:42	03:45	-	03:59
Period of daylight	21:13	15:31	24:00	15:59

- During daylight, vessel-based observers will watch for marine mammals near the seismic vessel during all periods of airgun activity and for a minimum of 30 min prior to the planned start of airgun operations after an extended shut down.
- Although there will only be a brief period during the survey when darkness will be encountered in U.S. waters, USGS proposes to conduct nighttime as well as daytime operations. Observers dedicated to protected species observations are proposed not 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.

Proposed Safety Radii

Mosher et al. (2009) collected received sound level data for the airgun configuration that will be used in the proposed survey in similar water depths, i.e. > 2000 m, The empirical data were plotted in relation to distance and direction from the 3-airguns by Roth and Schmidt (2010; Fig. B-3). Based on model fit to the measured received levels and source modeling estimates from Gundalf®, the 180 and 190 dB rms radii are estimated to be 216 m and 68 m, respectively. As a conservative measure for the proposed safety radii, the sound-level radii indicated by the empirical data have been increased to 500 m for the 180-dB isopleth and to 100 m for the 190-dB isopleth (Table 2).

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. These planned power-down and shut down criteria are consistent with guidelines listed for cetaceans and pinnipeds by NMFS (2000), and other guidance by NMFS.

Mitigation during Operations

In addition to monitoring, mitigation measures that will be adopted will include (1) speed or course alteration, provided that doing so will not compromise operational safety requirements, (2) power down or shut-down procedures, and (3) no start up of airgun operations unless the full 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 (which may be encountered starting in late August), 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 entire 180 dB safety radius is visible using vessel lights, 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 science objectives. The marine mammal activities and movements relative to the seismic vessel will be closely monitored to ensure that the marine mammal does not approach within the safety radius. If the mammal appears likely to enter the safety radius, further mitigative actions will be taken, i.e., either further course alterations or power down or shut down of the airgun(s).

Power-down Procedures

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

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 airgun array, the number of guns operating will be reduced to the single 150 in^3 G-airgun. The 180 dB (rms) safety radius around the power down source has been estimated to be 62 m, the proposed distance for use by PSOs is 75 m (Table 2) If a marine mammal is detected within or near the smaller safety radius around the single 150 in^3 G-airgun, all airguns will be shut down (see next subsection).

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

- is visually observed to have left the safety zone, or
- has not been seen within the zone for 15 min in the case of small odontocetes and pinnipeds, or

- has not been seen within the zone for 30 min in the case of mysticetes (large odontocetes do not occur within the study area).

Shut-down Procedures

The operating airgun(s) will be shut down completely if a marine mammal approaches or enters the then-applicable safety radius and a power down is not practical 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 150 in^3 G-gun) 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 (small odontocetes and 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” procedure will be followed when the airgun array begins operating after a specified-duration period with no or reduced airgun operations. The specified period depends on the speed of the source vessel, the size of the airgun array that is being used, and the size of the safety radii, but is often about 10 min.

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 USGS intends to follow NMFS’ guidelines with a ramp up rate of no more than 6 dB per 5 min period. A common procedure is to double the number of operating airguns at 5-min intervals. During the ramp-up, the safety zone for the full three G-gun array (or whatever smaller source might then be in use) will be maintained.

If the complete 180 dB safety radius has not been visible for at least 30 min prior to the planned start of a ramp-up in either daylight or nighttime, ramp up will not commence unless at least one airgun has been operating during that period. This means that it will not be permissible to ramp up the 3-G-gun array from a complete shut down in thick fog when the entire 180 dB safety zone is not visible. If the entire safety radius is visible using vessel lights, then start up of the airguns from a complete shut down may occur at night. If one airgun has operated during a power-down period, ramp up to full power will be permissible at night or in poor visibility, on the assumption that marine mammals will be alerted 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. Ramp up of the airguns will not be initiated during the day or at night if a marine mammal has been sighted within or near the applicable safety radius during the previous 15 or 30 min, as applicable.

Helicopter flights

The use of a helicopter to conduct ice reconnaissance flights and vessel-to-vessel personnel transfers is likely to occur during survey activities in U.S. waters. However, collection of spot bathymetry data or on-ice landings, both of which required low altitude flight patterns, will not occur in U.S. waters.

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.

The USGS has communicated with community authorities and residents of Barrow to foster understanding of the proposed survey. There are elements of the proposed survey, intrinsic to the project, that significantly limit the potential conflict with subsistence users. Operations will be conducted during early August before bowhead whale hunting typically occurs off Barrow and ~108 km offshore, farther offshore than traditional subsistence hunting grounds. USGS continues to work with the people of Barrow to identify and avoid areas of potential conflict.

- The USGS initiated contact with NSB scientists and the chair of the AEWC in mid-December 2010 via an emailed description of the proposed survey that included components intended to minimize potential subsistence conflict.
- Invitations were extended on 31 December 2009 to members of the NSB, AEWC and North Slope Communities to attend a teleconference arranged for 11 January 2010. The teleconference served as a venue to promote understanding of the project and discuss shareholder concerns. Participants in the teleconference included Harry Brower, chair of the AEWC, and NSB wildlife biologist Dr. Robert Suydam.
- To further promote cooperation between the project researchers and the community, Dr. Deborah Hutchinson with USGS presented the proposed survey at a meeting of the AEWC in Barrow on 11 February 2010. Survey plans were explained to local hunters and whaling captains, including NSB Department of Wildlife Management biologists, Craig George and Robert Suydam. Dr. Hutchinson consulted with stakeholders about their concerns and discussed the aspects of the survey designed to mitigate impacts.
- Dr. Deborah Hutchinson of the USGS emailed a summary of the topics discussed during the teleconference and the AEWC meeting in Barrow to representatives of the NSB, AEWC and North Slope communities. These included:
  - Surveying within U.S. waters is scheduled early (~7-12 August) to avoid conflict with hunters
  - The EA and IHA application will be distributed as early as possible to NSB and AEWC
  - A community observer will be present aboard the *Healy* during the project
  - Mitigation of the one crew transfer near Barrow in early September will be arranged – probably through Barrow Volunteer Search and Rescue
- Representatives of the USGS attended the Arctic Open-water Meeting in Anchorage, 22-24 March.
  - Dr. Deborah Hutchinson presented information regarding the proposed survey to the general assembly

  - Dr.s Jonathan Childs and Deborah Hutchinson met with stakeholders and agency representatives while at the meeting

Subsequent meetings with whaling captains, other community representatives, the AEWC, NSB, and any other parties to the plan will be held if necessary to coordinate the planned seismic survey operation with subsistence hunting activity. The USGS has informed the chairman of the Alaska Eskimo Whaling Committee (AEWC), Harry Brower, Jr., of its survey plan.

As noted above in § VIII, in the unlikely event that subsistence hunting or fishing is occurring within 5 km (3 mi) of the project vessel tracklines, or where potential impacts could occur, the airgun operations will be suspended until the vessel is >5 km away and otherwise not interfering with subsistence activities.

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...

USGS proposes to sponsor marine mammal monitoring during the proposed project, in order to implement the proposed mitigation measures that require real-time monitoring, to satisfy the anticipated monitoring requirements of the NMFS IHA, and to meet any monitoring requirements agreed to as part of the Plan of Cooperation.

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

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

Vessel-based Visual Monitoring

Vessel-based protected species observers (PSOs) will be stationed on both the *Louis S. St. Laurent* and the *Healy* during the proposed survey. The vessels will typically work together in tandem while making way through heavy ice with the *Healy* in lead breaking ice and collecting multibeam data. The *Louis S. St. Laurent* will follow collecting seismic reflection and refraction data. In light ice conditions, the vessels will separate to maximize data collection. "Real-time" communication between the two vessels regarding marine mammal detections will be available through VHF radio.

During operations in U.S. EEZ waters, a complement of five observers will work on the source vessel, the *Louis S. St. Laurent*, and two will be stationed on the *Healy*. Three trained PSOs, knowledgeable about marine mammals of the Arctic, will be recruited through a Canadian Hunters and Trappers Committee to work on the *Louis S. St. Laurent*. These observers will board the *Louis S. St.*

Laurent in Kugluktuk, Nunavut, Canada. Three experienced PSOs and one Alaska Native community observer will be aboard the *Healy* at the outset of the project. Before survey operations begin in U.S. waters, two of the PSOs on the *Healy* will transfer to the *Louis S. St. Laurent* to provide additional observers during airgun operations. When not surveying in U.S. waters, the distribution of PSOs will return to three on the *Louis S. St. Laurent* and four on the *Healy*.

PSOs on the *Louis S. St. Laurent* will monitor for marine mammals during all daylight airgun operations. Airgun operations will be shut down when marine mammals are observed within, or about to enter, designated safety radii (see below) where there may be a possibility of significant effects on hearing or other physical effects. PSOs on both the source vessel and the *Healy* will also watch for marine mammals within or near the safety radii for at least 30 min prior to the planned start of airgun operations after an extended shut down of the airgun array. When feasible, observations will also be made during periods without seismic operations (e.g., during transits). Environmental conditions will be recorded every half hour during PSO watch.

The PSOs aboard the *Healy* will also watch for marine mammals during daylight seismic activities conducted in both U.S. and international waters. They will maximize their time on watch but will not watch continuously, as will those on the *Louis S. St. Laurent*, because they will not have mitigation duties and there will be only two PSOs aboard the *Healy*. The *Healy* PSOs will report sightings to the PSOs on the *Louis S. St. Laurent* to alert them of possible needs for mitigation.

In U.S. waters, at least one observer, and when practical two observers, will monitor for marine mammals from the *Louis S. St. Laurent* during ongoing daytime operations and nighttime start ups (when darkness is encountered). Use of two simultaneous observers will increase the proportion of the animals present near the source vessel that are detected. PSOs will normally be on duty in shifts of no longer than 4 hours duration although more than one 4-hr shift may be worked per day with a maximum of 12 hr of daily watch time. During seismic operations in international waters, PSOs aboard the *Louis S. St. Laurent* will conduct 8-hr watches. This schedule accommodates 24-hr/day monitoring by three PSOs which will be necessary during most of the survey when daylight will be continuous. *Healy* PSOs will limit watches to 4 hours in U.S. waters.

The *Louis S. St. Laurent* crew will be instructed to assist in detecting marine mammals and implementing required mitigation (if practical). The crew will be given instruction on mitigation requirements and procedures for implementation of mitigation prior to the start of the seismic survey. Members of the *Healy* crew will be trained to monitor for marine mammals and asked to contact the *Healy* observers for sightings that occur while the PSOs are off-watch.

The *Louis S. St. Laurent* and *Healy* are suitable platforms for protected species observations. When stationed on the flying bridge, eye level will be ~15.4 m (51 ft) above sea level on the *Louis S. St. Laurent* and ~24 m (78.7 ft) above sea level on the *Healy*. On both vessels the observer will have an unobstructed view around the entire vessel from the flying bridge. If surveying from the bridge of the *Louis S. St. Laurent* or the *Healy*, the observer's eye level will be 12.1 m (~40 ft) above sea level or 21.2 m (69 ft) above sea level, respectively. The PSO(s) will scan the area around the vessel systematically with laser range finding binoculars and with the unaided eye.

The survey will be conducted at high latitudes and continuous daylight will persist through much of the proposed survey area through the month of August. Day length will decrease to ~18 hr in the northern portion of the survey area by about early September. Laser range-finding binoculars (Leica LRF 1200 laser rangefinder or equivalent) will be available to assist with distance estimation; this equipment is useful in training observers to estimate distances visually, but is generally not useful in measuring distances to animals directly.

When mammals are detected within or about to enter the designated safety radius, the airgun(s) will be powered down or shut down immediately. The distinction between power downs and shut downs is described in section II(3)(c) below. Channels of communication between the PSOs and the airgun technicians will be established to assure prompt implementation of shutdowns when necessary as has been done in other recent seismic survey operations in the Arctic (e.g., Haley 2006). During power downs and shutdowns, PSOs will continue to maintain watch to determine when the animal(s) are outside the safety radius. Airgun operations will not resume until the animal is outside the safety radius. The animal will be considered to have cleared the safety radius if it is visually observed to have left the safety radius. Alternatively, in U.S. waters the safety zone will be considered clear if the animal has not been seen within the radius for 15 min for small odontocetes and pinnipeds or 30 min for mysticetes. Within international waters, the PSOs will apply a 30 minute period for all species.

All observations and airgun power downs or shut downs in U.S. waters will be recorded in a standardized format. Data will be entered into a custom database using a notebook computer. The accuracy of the data entry will be verified by manual checking of the database.

Results from the vessel-based observations will provide

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

Reporting

A report on USGS activities and on the relevant monitoring and mitigation results will be submitted to NMFS within 90 days after the end of the cruise. The report will describe the operations that were conducted, and the cetaceans and seals that were detected near the operations. The report will be submitted to NMFS, providing full documentation of methods, results, and interpretation pertaining to all acoustic characterization work and vessel-based monitoring. The 90-day report will summarize the dates and locations of seismic operations, and all cetacean and seal sightings (dates, times, locations, activities, associated seismic survey activities). The number and circumstances of ramp ups, power downs, shutdowns, and other mitigation actions will be reported. Sample size permitting, the report will also include estimates of the amount and nature of potential “take” of cetaceans and seals by harassment or in other ways.

XIV. COORDINATING RESEARCH TO REDUCE AND EVALUATE INCIDENTAL TAKE

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

USGS will coordinate the planned marine mammal monitoring program associated with the seismic survey in the Arctic Ocean with other parties that may have interest in this area and/or be conducting marine mammal studies in the same region during operations. No other marine mammal studies are expected to occur in the main (northern) parts of the study area at the proposed time. However, other industry-funded seismic surveys may be occurring in the northeast Chukchi and/or western Beaufort Sea closer to shore, and those projects are likely to involve marine mammal monitoring.

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

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APPENDIX A:

DESCRIPTION OF VESSELS PROPOSED FOR THE 2010 GEOPHYSICAL PROJECT [1]

LOUIS S. ST. LAURENT

Photo of Louis S. St-Laurent available online at:
http://www.ccg-gcc.gc.ca/eng/Fleet/Vessels?id=1111&info=5&subinfo=4

The Canadian Coast Guard Ship (CCGS) *Louis S. St. Laurent* was built in 1969 by Canadian Vickers Ltd. in Montreal, Quebec, and underwent an extensive modernization in Halifax, Nova Scotia between 1988-1993.

The *Louis S. St-Laurent* is based at CCG Base Dartmouth in Dartmouth, Nova Scotia. Current vessel activities involve summer voyages to the Canadian Arctic for sealifts to various coastal communities and scientific expeditions. A description of the *Louis S. St-Laurent* with vessel specifications is presented below and is available online at:

http://www.ccg-gcc.gc.ca/eng/Fleet/Vessels?id=1111&info=5&subinfo

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

CCGS *Louis S. St. Laurent* Ship Characteristics

Length:	119.8 m	**Breadth:**	24.38 m
Draft:	9.91 m	**Freeboard:**	6.4 m
Hold 1:	300 m3	**Hatch Size 1 (l x w):**	3.5 m X 3 m
Hold 2:	36 m3	**Hatch Size 2 (l x w):**	3.5 m X 3 m
Main Deck Area:	320 m2	**Boat Deck Area:**	216 m2
Forcastle:	N/A	**After Deck Area:**	120 m2
Gross Tonnage:	11345 grt	**Net Tonnage:**	3403 nrt
Cruising Speed:	16 kts	**Max. Speed:**	20 kts
Cruising Range:	23000 nm	**Endurance:**	205 days
Fuel Consumption:	24 m3/day	**Fuel Capacity:**	4800 m3
Fresh Water:	200 m3		

Propulsion:	Diesel electric AC/DC
Description:	(5x) Krupp Mak 16M453C (3x) GE DC Motor
Power:	20142 Kw
Propellers:	3 - fixed pitch
Generators:	(2x) Krupp Mak 6M282 @ 1100kw
Emergency Gen.:	(1x) Caterpillar 3408 BDI
Bow:	Yes
Stern:	No
UPS:	No

Flight Deck Area:	360 m2	**Hangar Area:**	132 m2
Hangar Gear:	Yes	**Fuel Capacity:**	40 m3

HEALY

The Coast Guard Cutter *Healy* is United States' newest and most technologically advanced polar icebreaker. A description with vessel specifications for the *Healy* is available online at: http://www.uscg.mil/pacarea/cgcHealy/default.asp

The *Healy* is designed to conduct a wide range of research activities, providing more than 4,200 square feet of scientific laboratory space, numerous electronic sensor systems, oceanographic winches, and accommodations for up to 50 scientists. The *Healy* is designed to break 4.5 ft of ice continuously at three knots and can operate in temperatures as low as -50 degrees F. The science community provided invaluable input on lab lay-outs and science capabilities during design and construction of the ship. The *Healy* is also a capable platform for supporting other potential missions in the polar regions, including logistics, search and rescue, ship escort, environmental protection, and enforcement of laws and treaties.

The *Healy* is a USCG icebreaker, capable of traveling at 5.6 km/h (3 knots) through 1.4 m of ice. A “Central Power Plant”, four Sultzer 12Z AU40S diesel generators, provides electric power for propulsion and ship’s services through a 60 Hz, 3-phase common bus distribution system. Propulsion power is provided by two electric AC Synchronous, 11.2 MW drive motors, fed from the common bus through a Cycloconverter system, that turn two fixed-pitch, four-bladed propellers.

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

Other details of the *Healy* include the following:

Owner:	USCG
Operator:	USCG
Flag:	United States of America

Launch Date:	15 November 1997
Bathymetric Survey Systems:	Kongsberg EM122 Bottom Mapping Echo sounder, Knudsen 320 B/R Sub Bottom Profiler
Compressors for Air Guns:	2 portable compressors, capacity of 3964 L/min
Accommodation Capacity:	138 including ~50 scientists

CGC *Healy* Ship Characteristics

Length, Overall	420'0" (128 meters)
Beam, Maximum	82'0" (25 meters)
Draft, Full Load	29'3" (8.9 meters)
Displacement, Full Load	16,000 LT
Propulsion	Diesel Electric, AC/AC Cycloconvertor
Generating Plant	4 Sultzer 12Z AU40S
Drive Motors	2 AC Synchronous, 11.2 MW
Shaft Horsepower	30,000 Max HP
Propellers	2 Fixed Pitch, 4 Bladed
Auxiliary Generator	EMD 16-645F7B, 2400kW
Fuel Capacity	1,220,915 GAL (4,621,000 liters)
Cruising Speed	12 knots @ 105 RPM
Max Speed	17 knots @ 147 RPM
Icebreaking Capability	4.5ft @ 3 knots (continuous) 8 ft (2.44 m) Backing and Ramming
Science Labs	Main, Bio-Chemical, Electronics, Meteorological, Photography
Accommodations	19 Officer, 12 CPO, 54 Enlisted, 35 Scientists, 15 Surge, 2 Visitors

APPENDIX B:

DESCRIPTION OF SOUND SOURCES AND SAFETY RADII

AIRGUN DESCRIPTION AND SAFETY RADII

The seismic source for the proposed geophysical survey will be comprised of three Sercel G-guns with a total volume an 1150 in^3. The three-gun array will be comprised of two 500-in^3 and one 150 in^3 G-guns in a triangular configuration (Fig. B-1). The single 150-in^3 G-gun will be used if a power down is necessary for mitigation. The G-gun array will be towed behind the *Louis S. St. Laurent* at a depth of ~11 m (Fig. B-2) along predetermined lines in water depths ranging from 1900-4000 m. One streamer ~232 m in length with a single hydrophone will be towed behind the airgun array at a depth of ~9 to 30 m.

A square wave trigger signal will be supplied to the firing system hardware by a FEI-Zyfer GPStarplus Clock model 565, based on GPS time (typically at ~14 to 20 sec intervals). Vessel speed will be ~5.5 kt resulting in a shot interval ranging from ~39 to 56 m. G-gun firing and synchronization will be controlled by a RealTime Systems LongShot fire controller, which will send a voltage to the gun solenoid to trigger firing with ~54.8 ms delay between trigger and fire point.

Pressurized air for the pneumatic G-guns will be supplied by two Hurricane compressors, model 6T-276-44SB/2500. These are air cooled, containerized compressor systems. Each compressor will be powered by a C13 Caterpillar engine which turns a rotary screw first stage compressor and a three stage piston compressor capable of developing a total air volume of 600 SCFM @ 2500 PSI. The seismic system will be operated at 1950 PSI and one compressor could easily supply sufficient volume of air under appropriate pressure.

Seismic acquisition will require a watchkeeper in the seismic lab and another in the compressor container. The seismic lab watchkeeper is responsible for data acquisition/recording, watching over-the-side equipment, gun firing and log keeping. A remote screen will permit monitoring of compressor pressures and alerts, as well as communication with the compressor watchkeeper. The compressor watchkeeper will be required to monitor the compressor for any emergency shut down and provide general maintenance that might be required during operations.

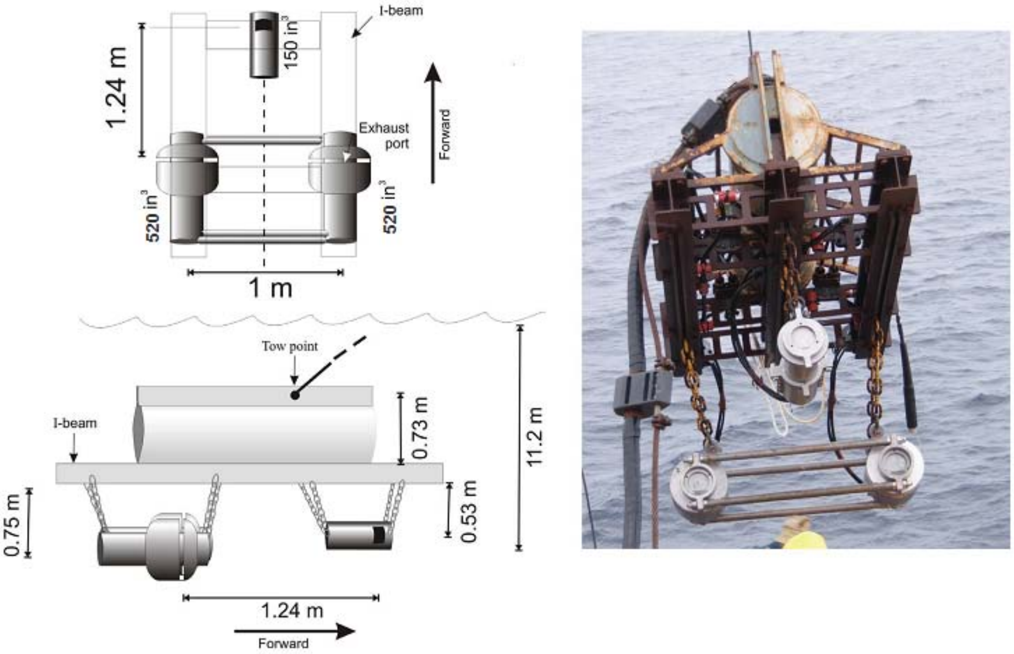


Figure B-1. Peak amplitude (in dB) of seismic traces (both peak positive and peak negative) compared with a 20LogR geometrical spreading loss curve (source: Mosher: et al. 2009).

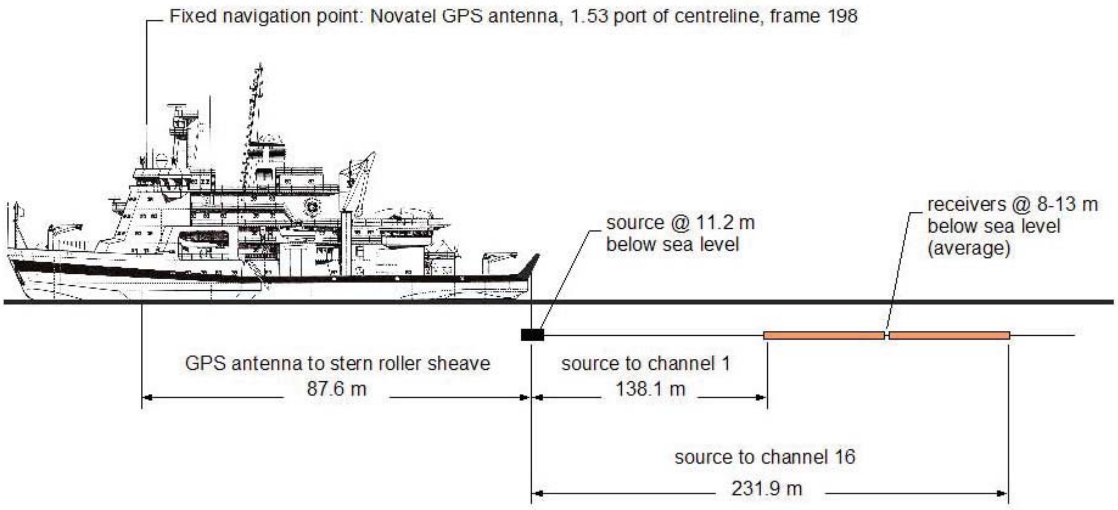


Figure B-2. Geometric arrangement of the seismic source and streamer (source Mosher et al. 2009).

Sound level radii of the proposed three-airgun array were measured in 2009 during a seismic calibration experiment (Mosher et al. 2009, Roth and Schmidt 2010). A transmission loss model was then constructed assuming spherical (20LogR) spreading and using the source level estimate (235 dB re 1 µPa 0-peak; 225 dB re 1 µPa rms) from the measurements. The use of 20LogR spreading fit the data well out to ~1 km where variability in measured values increased (see Appendix B for more details and a figure of the transmission loss model compared to the measurement data). Additionally, the Gundalf® modeling package was used to model the airgun array and estimated a source level output of 236.7 dB 0-peak (226.7 dB rms). Using this slightly stronger source level estimate and 20LogR spreading the 180 and 190 dB rms radii are estimated to be 216 m and 68 m, respectively. As a conservative measure for the proposed safety radii, the sound-level radii indicated by the empirical data and source models have been increased to 500 m for the 180-dB isopleth and to 100 m for the 190-dB isopleth (Table 2).

TABLE B-1. Sound level radii for the three-airgun array and mitigation airgun for the proposed USGS seismic survey (precautionary estimates based on Gundalf® source modeling and Roth and Schmidt 2010).

[redacted]

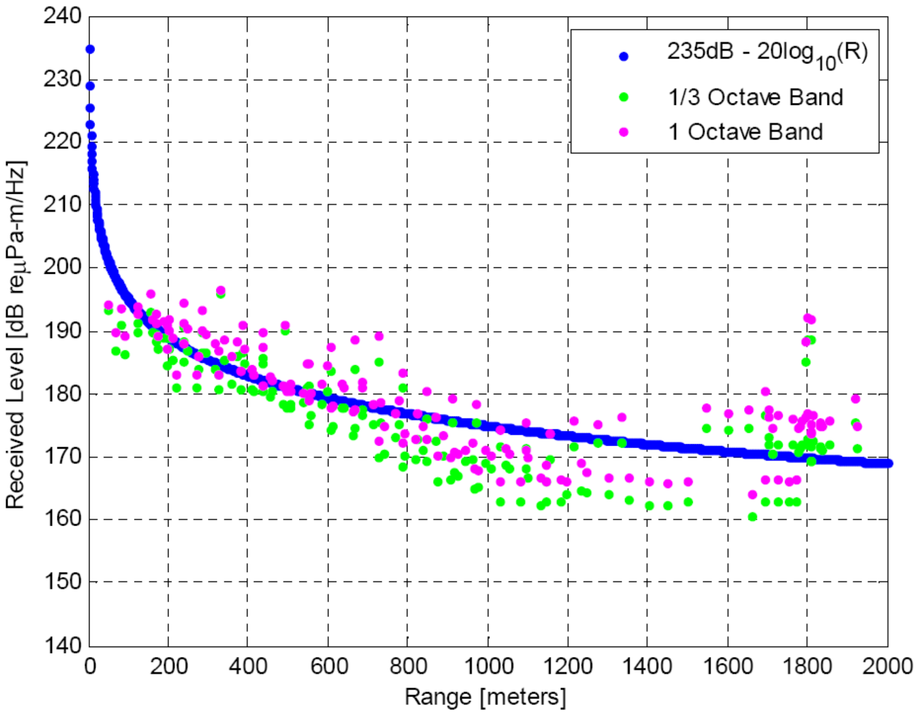


Figure B-3. Measured peak sound pressure levels as a function of range for 1/3 and full octave bands. The blue line shows theoretical spherical spreading loss for a 235 dB marine source as a comparison (Roth and Schmidt 2010).

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

OTHER ACOUSTIC DEVICES

Along with the airgun operations, additional acoustic systems to be operated during the cruise will include a 12-kHz Chirp echo sounder and a 3–5 kHz sub-bottom profiler from the *Louis S. St. Laurent.* The *Healy* will operate a 12-kHz Kongsberg multibeam bathymetric echo sounder, a Knudsen 320BR profiler, a piloting echo sounder and two acoustic Doppler current profilers. These sources will operate throughout most of the cruise to map the bathymetry, as necessary, to meet the geophysical science objectives. During seismic operations, these sources will be deployed from the *Louis S. St. Laurent* and the *Healy* and will generally operate simultaneously with the airgun array deployed from the *Louis S. St. Laurent*.

Echo Sounder (Knudsen 320BR)

Along with the airgun operations, an additional acoustic system to be operated during the cruise will include a 12-kHz Knudsen echo sounder. The Knudsen 320BR will provide information on depth and bottom profile. The Knudsen 320BR is a dual–frequency system with operating frequencies of 3.5 and 12 kHz, however, the unit will be functioning at the higher frequence, 12 kHz, because the 3.5 kHz transducer is not installed.

While the Knudsen 320BR operates at 12 kHz, its calculated maximum source level (downward) is 215 dB re 1 µPa at 1 m. The pulse duration is typically 1.5 to 5 ms with a bandwidth of 3 kHz (FM sweep from 3 kHz to 6 kHz). The repetition rate is range dependent, but the maximum is a 1% duty cycle. Typical repetition rate is between 1/2 s (in shallow water) to 8 s in deep water.

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

Towed 3–5 kHz Chirp Sub-bottom Profiler (Knudsen 3260)

The 3–5 kHz chirp sub-bottom profiler will be towed by and operated from the *Louis S. St. Laurent* in open water when the *Louis S. St. Laurent* is not working in tandem with the *Healy.* The profiler provides information about sedimentary features and bottom topography. The chirp system has a maximum 7.2 kW transmit capacity into the towed array. The energy from the towed unit is directed downward by an array of eight transducers in a conical beamwidth of 80°. The interval between pulses will be no less than one pulse per second. Sub-bottom profilers of that frequency can produce sound levels of 200-230 dB re 1 µPa at 1 m (Richardson et al. 1995).

Multibeam Echosounder (Kongsberg EM122)

The Kongsberg EM 122 MBES operates at 10.5–13 (usually 12) kHz and is hull-mounted on the *Healy*. The transmitting beamwidth is 1° fore–aft and 150° athwartship. The maximum source level is 242 dB re 1 μPa·m_{rms}. Each "ping" consists of eight (in water >1000 m deep) or four (<1000 m) successive fan-shaped transmissions, each ensonifying a sector that extends 1° fore–aft. Continuous-wave (CW) pulses increase from 2 to 15 ms long in water depths up to 2600 m, and FM chirp pulses up to 100 ms long are used in water >2600 m. The successive transmissions span an overall cross-track angular extent of about 150°, with 2-ms gaps between the pulses for successive sectors.

Hydrographic Sub-bottom Profiler (Knudsen 320BR)

The Knudsen 320BR will provide information on sedimentary layering, down to between 20 and 70 m, depending on bottom type and slope. The Knudsen 320BR is a dual–frequency system with operating frequencies of 3.5 and 12 kHz; only the low frequency will be used during this survey. At 3.5 kHz, the maximum output power into the transducer array, as wired on the *Healy* (where the array impedance is approximately125 ohms), is ~6000 watts (electrical), which results in a maximum source level of 221 dB re 1 μPa at 1 m downward. Pulse lengths range from 1.5 to 24 ms with a bandwidth of 3 kHz (FM sweep from 3 kHz to 6 kHz). The repetition rate is range dependent, but the maximum is a 1% duty cycle. Typical repetition rate is between ½ s (in shallow water) to 8 s in deep water.

The 3.5-kHz transducer array on the *Healy*, consisting of 16 (TR109) elements in a 4 × 4 array, will be used for the Knudsen 320BR. At 3.5-kHz the SBP emits a downward conical beam with a width of approximately 26°.

Piloting Echosounder

The piloting echo sounder on the Healy is an Ocean Data Equipment Corporation (ODEC) Bathy-1500 will provide information on water depth below the vessel. The ODEC system has a maximum 2-kW transmit capacity into the transducer and has two operating modes, single or interleaved dual frequency, with available frequencies of 12, 24, 33, 40, 100, and 200 kHz.

Acoustic Doppler Current Profiler (R D Instruments Ocean Surveyor 150 kHz)

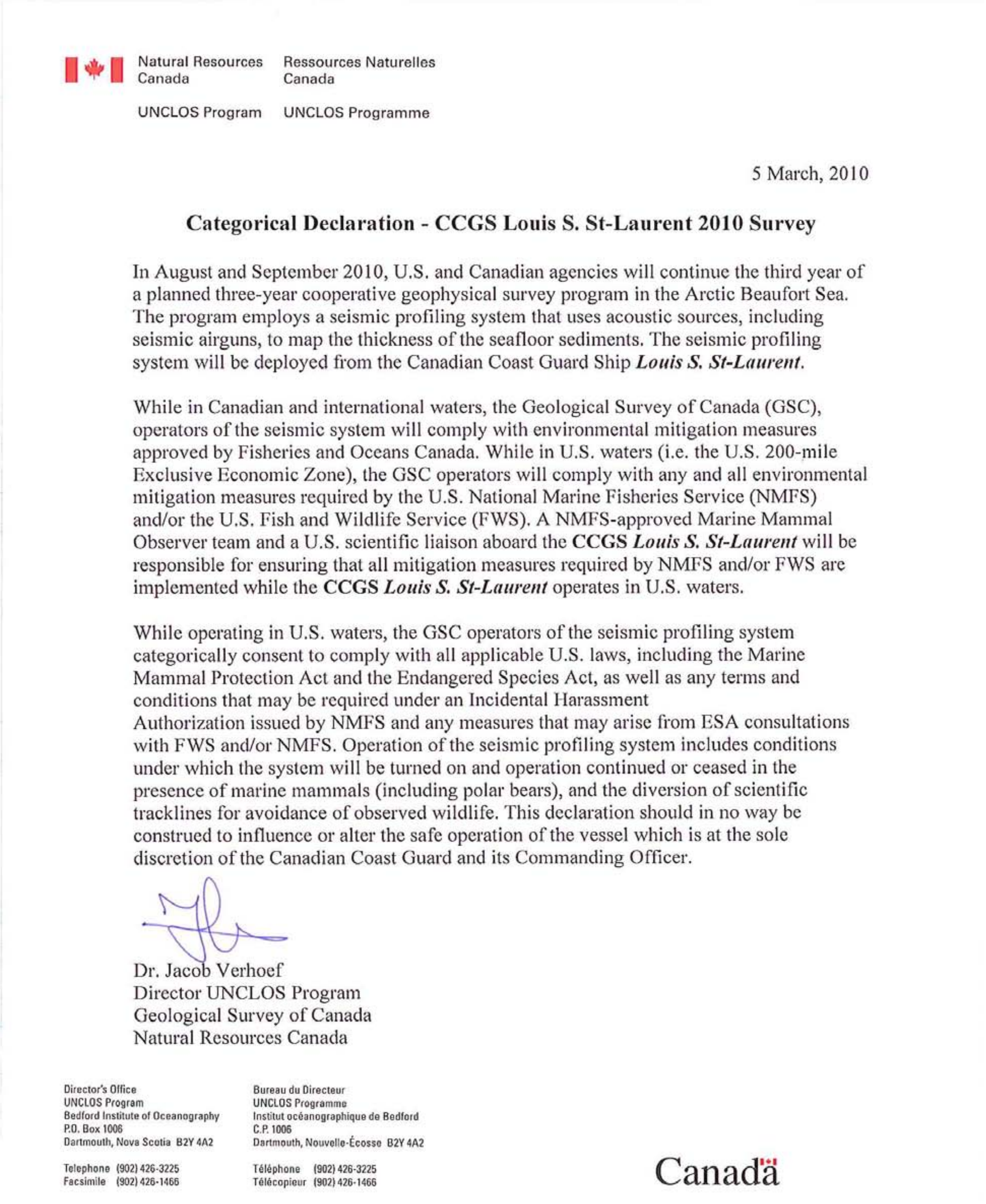
The 150-kHz acoustic Doppler current profiler (ADCP™) has a minimum ping rate of 0.65 ms. There are four beam sectors and each beamwidth is 3°. The pointing angle for each beam is 30° off from vertical with one each to port, starboard, forward, and aft. The four beams do not overlap. The 150-kHz ADCP's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

Acoustic Doppler Current Profiler (R D Instruments Ocean Surveyor 75)

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

APPENDIX C:

CANADIAN GEOLOGICAL SURVEY CATEGORICAL DECLARATION



Natural Resources Canada | Ressources Naturelles Canada

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5 March, 2010

Categorical Declaration - CCGS Louis S. St-Laurent 2010 Survey

In August and September 2010, U.S. and Canadian agencies will continue the third year of a planned three-year cooperative geophysical survey program in the Arctic Beaufort Sea. The program employs a seismic profiling system that uses acoustic sources, including seismic airguns, to map the thickness of the seafloor sediments. The seismic profiling system will be deployed from the Canadian Coast Guard Ship ***Louis S. St-Laurent***.

While in Canadian and international waters, the Geological Survey of Canada (GSC), operators of the seismic system will comply with environmental mitigation measures approved by Fisheries and Oceans Canada. While in U.S. waters (i.e. the U.S. 200-mile Exclusive Economic Zone), the GSC operators will comply with any and all environmental mitigation measures required by the U.S. National Marine Fisheries Service (NMFS) and/or the U.S. Fish and Wildlife Service (FWS). A NMFS-approved Marine Mammal Observer team and a U.S. scientific liaison aboard the **CCGS *Louis S. St-Laurent*** will be responsible for ensuring that all mitigation measures required by NMFS and/or FWS are implemented while the **CCGS *Louis S. St-Laurent*** operates in U.S. waters.

While operating in U.S. waters, the GSC operators of the seismic profiling system categorically consent to comply with all applicable U.S. laws, including the Marine Mammal Protection Act and the Endangered Species Act, as well as any terms and conditions that may be required under an Incidental Harassment Authorization issued by NMFS and any measures that may arise from ESA consultations with FWS and/or NMFS. Operation of the seismic profiling system includes conditions under which the system will be turned on and operation continued or ceased in the presence of marine mammals (including polar bears), and the diversion of scientific tracklines for avoidance of observed wildlife. This declaration should in no way be construed to influence or alter the safe operation of the vessel which is at the sole discretion of the Canadian Coast Guard and its Commanding Officer.

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APPENDIX D:

REVIEW OF THE EFFECTS OF AIRGUN AND SONAR SOUNDS ON MARINE MAMMALS

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).

3. The ability to determine sound direction at the frequencies under consideration.

4. The ability to discriminate among sounds of different frequencies and intensities.

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

2.1 Toothed Whales (Odontocetes)

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

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

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

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

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

2.2 Baleen Whales (Mysticetes)

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

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

2.3 Seals and Sea Lions (Pinnipeds)

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

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

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

2.4 Manatees and Dugong (Sirenians)

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

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

2.5 Sea Otter and Polar Bear

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

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

3. CHARACTERISTICS OF AIRGUN SOUNDS

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

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

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

The strengths of airgun pulses can be measured in different ways, and it is important to know which method is being used when interpreting quoted source or received levels. Geophysicists usually quote peak-to-peak (p-p) levels, in bar-meters or (less often) dB re 1 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.[2] 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 travel-

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[2] 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).

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

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

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

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

4. MASKING EFFECTS OF AIRGUN SOUNDS

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

Clark and Gagnon 2006). Situations with prolonged strong reverberation are infrequent, in our experience. However, it is common for reverberation to cause some lesser degree of elevation of the background level between airgun pulses (e.g., Guerra et al. 2009), and this weaker reverberation presumably reduces the detection range of calls and other natural sounds to some degree.

Although masking effects of pulsed sounds on marine mammal calls and other natural sounds are expected to be limited, there are few specific studies on this. Some whales continue calling in the presence of seismic pulses and whale calls often can be heard between the seismic pulses (e.g., Richardson et al. 1986; McDonald et al. 1995; Greene et al. 1999a,b; Nieukirk et al. 2004; Smultea et al. 2004; Holst et al. 2005a,b, 2006; Dunn et al. 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 $\mu Pa_{pk\text{-}pk}$. 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. Malme et al. (1985) concluded that there was no clear evidence of avoidance, despite the possibility of subtle effects, at received levels up to 172 re 1 µPa on an approximate rms basis.

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

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

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

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

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

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

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

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

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

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

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

In a study off Nova Scotia, Moulton and Miller (2005) found little difference in sighting rates (after accounting for water depth) and initial average sighting distances of balaenopterid whales when airguns were operating (mean = 1324 m) vs. silent (mean = 1303 m). However, there were indications that these whales were more likely to be moving away when seen during airgun operations. Baleen whales at the average sighting distance during airgun operations would have been exposed to sound levels (via direct path) of about 169 dB re 1 μPa_{rms} (Moulton and Miller 2005). Similarly, ship-based monitoring studies of blue, fin, sei and minke whales offshore of Newfoundland (Orphan Basin and Laurentian Sub-basin) found no more than small differences in sighting rates and swim directions during seismic vs. non-seismic periods (Moulton et al. 2005, 2006a,b). Analyses of CPA data yielded variable results.[3] 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

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[3] 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.

levels out to much longer distances. However, studies done since the late 1990s of migrating humpback and migrating bowhead whales show reactions, including avoidance, that sometimes extend to greater distances than documented earlier. Avoidance distances often exceed the distances at which boat-based observers can see whales, so observations from the source vessel can be biased. Observations over broader areas may be needed to determine the range of potential effects of some large-source seismic surveys where effects on cetaceans may extend to considerable distances (Richardson et al. 1999; Bain and Williams 2006; Moore and Angliss 2006). Longer-range observations, when required, can sometimes be obtained via systematic aerial surveys or aircraft-based observations of behavior (e.g., Richardson et al. 1986, 1999; Miller et al. 1999, 2005; Yazvenko et al. 2007a,b) or by use of observers on one or more support vessels operating in coordination with the seismic vessel (e.g., Smultea et al. 2004; Johnson et al. 2007). However, the presence of other vessels near the source vessel can, at least at times, reduce sightability of cetaceans from the source vessel (Beland et al. 2009), thus complicating interpretation of sighting data.

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

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

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

Data on short-term reactions by cetaceans to impulsive noises are not necessarily indicative of long-term or biologically significant effects. It is not known whether impulsive sounds affect reproductive rate or distribution and habitat use in subsequent days or years. However, gray whales have continued to migrate annually along the west coast of North America despite intermittent seismic exploration (and much ship traffic) in that area for decades (Appendix A *in* Malme et al. 1984; Richardson et al. 1995), and there has been a substantial increase in the population over recent decades (Angliss and Outlaw 2008). The western Pacific gray whale population did not seem affected by a seismic survey in its feeding ground during a prior year (Johnson et al. 2007). Similarly, bowhead whales have continued to travel to the eastern Beaufort Sea each summer despite seismic exploration in their summer and autumn range for many years (Richardson et al. 1987), and their numbers have increased notably (Angliss and Outlaw 2008). Bowheads also have been observed over periods of days or weeks in areas ensonified repeatedly by seismic pulses (Richardson et al. 1987; Harris et al. 2007). However, it is generally not known whether the same individual bowheads were involved in these repeated observations (within and between years) in strongly ensonified areas. In any event, in the absence of some unusual circumstances, the history of coexistence between seismic surveys and baleen whales suggests that brief exposures to sound pulses from any single seismic survey are unlikely to result in prolonged effects.

5.2 Toothed Whales

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

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

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

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

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

Observers stationed on seismic vessels operating off the U.K. from 1997 to 2000 have provided data on the occurrence and behavior of various toothed whales exposed to seismic pulses (Stone 2003; Gordon et al. 2004; Stone and Tasker 2006). Dolphins of various species often showed more evidence of avoidance of operating airgun arrays than has been reported previously for small odontocetes. Sighting rates of white-sided dolphins, white-beaked dolphins, *Lagenorhynchus* spp., and all small odontocetes combined were significantly lower during periods when large-volume[4] airgun arrays were shooting. Except for the pilot whale and bottlenose dolphin, CPA distances for all of the small odontocete species tested, including killer whales, were significantly farther from large airgun arrays during periods of shooting compared with periods of no shooting. Pilot whales were less responsive than other small odontocetes in the presence of seismic surveys (Stone and Tasker 2006). For small odontocetes as a group, and most individual species, orientations differed between times when large airgun arrays were operating vs. silent, with significantly fewer animals traveling towards and/or more traveling away from the vessel during shooting (Stone and Tasker 2006). Observers' records suggested that fewer cetaceans were feeding and fewer were interacting with the survey vessel (e.g., bow-riding) during periods with airguns operating, and small odontocetes tended to swim faster during periods of shooting (Stone and Tasker 2006). For most types of small odontocetes sighted by observers on seismic vessels, the median CPA distance was ≥0.5 km larger during airgun operations (Stone and Tasker 2006). Killer whales appeared to be more tolerant of seismic shooting in deeper waters.

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

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

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

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

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

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

Reactions of toothed whales to a single airgun or other small airgun source are not well documented, but tend to be less substantial than reactions to large airgun arrays (e.g., Stone 2003; Stone and Tasker 2006). During 91 site surveys off the U.K. in 1997–2000, sighting rates of all small odontocetes combined were significantly lower during periods the low-volume[5] airgun sources were operating, and effects on orientation were evident for all species and groups tested (Stone and Tasker 2006). Results from four NSF-funded L-DEO seismic surveys using small arrays (up to 3 GI guns and 315 in^3) were inconclusive. During surveys in the Eastern Tropical Pacific (Holst et al. 2005b) and in the Northwest Atlantic (Haley and Koski 2004), detection rates were slightly lower during seismic compared to non-seismic periods. However, mean CPAs were closer during seismic operations during one cruise (Holst et al. 2005b), and greater during the other cruise (Haley and Koski 2004). Interpretation of the data was confounded by the fact that survey effort and/or number of sightings during non-seismic periods during both surveys was small. Results from another two small-array surveys were even more variable (MacLean and Koski 2005; Smultea and Holst 2008).

Captive bottlenose dolphins and beluga whales exhibited changes in behavior when exposed to strong pulsed sounds similar in duration to those typically used in seismic surveys (Finneran et al. 2000, 2002, 2005). Finneran et al. (2002) exposed a captive bottlenose dolphin and beluga to single impulses from a water gun (80 in^3). As compared with airgun pulses, water gun impulses were expected to contain proportionally more energy at higher frequencies because there is no significant gas-filled bubble, and

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

thus little low-frequency bubble-pulse energy (Hutchinson and Detrick 1984). The captive animals sometimes vocalized after exposure and exhibited reluctance to station at the test site where subsequent exposure to impulses would be implemented (Finneran et al. 2002). Similar behaviors were exhibited by captive bottlenose dolphins and a beluga exposed to single underwater pulses designed to simulate those produced by distant underwater explosions (Finneran et al. 2000). It is uncertain what relevance these observed behaviors in captive, trained marine mammals exposed to single transient sounds may have to free-ranging animals exposed to multiple pulses. In any event, the animals tolerated rather high received levels of sound before exhibiting the aversive behaviors mentioned above.

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

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

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

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

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

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

Recent and more extensive data from vessel-based monitoring programs in U.K. waters and off Newfoundland and Angola suggest that sperm whales in those areas show little evidence of avoidance or behavioral disruption in the presence of operating seismic vessels (Stone 2003; Stone and Tasker 2006; Moulton et al. 2005, 2006a; Weir 2008a). Among sperm whales off Angola (n = 96 useable groups), there were no significant differences in encounter rates (sightings/hr) when a 24-airgun array (3147 in^3 or

5085 in^3) was operating vs. silent (Weir 2008a). There was also no significant difference in the CPA distances of the sperm whale sightings when airguns were on vs. off (means 3039 m vs. 2594 m, respectively). Encounter rate tended to increase over the 10-month duration of the seismic survey. These types of observations are difficult to interpret because the observers are stationed on or near the seismic vessel, and may underestimate reactions by some of the more responsive animals, which may be beyond visual range. However, these results do seem to show considerable tolerance of seismic surveys by at least some sperm whales. Also, a study off northern Norway indicated that sperm whales continued to call when exposed to pulses from a distant seismic vessel. Received levels of the seismic pulses were up to 146 dB re 1 $\mu Pa_{p\text{-}p}$ (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).[6] 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.

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 $\mu Pa_{pk\text{-}pk}$ 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.

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[6] 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).

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

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

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

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

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

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

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

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

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

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

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

6.2 Permanent Threshold Shift (PTS)

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

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

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

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

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

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

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

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

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

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

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

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

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

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

6.3 Strandings and Mortality

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

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

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

There is no conclusive evidence of cetacean strandings or deaths at sea as a result of exposure to seismic surveys, but a few cases of strandings in the general area where a seismic survey was ongoing have led to speculation concerning a possible link between seismic surveys and strandings. • Suggestions that there was a link between seismic surveys and strandings of humpback whales in Brazil (Engel et al. 2004) were not well founded (IAGC 2004; IWC 2007). • In Sept. 2002, there was a stranding of two Cuvier's beaked whales in the Gulf of California, Mexico, when the L-DEO seismic vessel R/V *Maurice Ewing* was operating a 20-airgun, 8490-in^3 airgun array in the general area. The evidence linking the stranding to the seismic survey was inconclusive and not based on any physical evidence (Hogarth 2002; Yoder 2002). The ship was also operating its multibeam echo sounder 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.

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APPENDIX E:

REVIEW OF THE EFFECTS OF AIRGUN SOUNDS ON FISHES[7]

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

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

1. ACOUSTIC CAPABILITIES

Sensory systems – like those that allow for hearing – provide information about an animal’s physical, biological, and social environments, in both air and water. Extensive work has been done to understand the structures, mechanisms, and functions of animal sensory systems in aquatic environments (Atema et al. 1988; Kapoor and Hara 2001; Collin and Marshall 2003). All fish species have hearing and skin-based mechanosensory systems (inner ear and lateral line systems, respectively) that provide information about their surroundings (Fay and Popper 2000). Fay (2009) and some others refer to the ambient sounds to which fishes are exposed as ‘underwater soundscapes’. Anthropogenic sounds can have important negative consequences for fish survival and reproduction if they disrupt an individual’s ability to sense its soundscape, which often tells of predation risk, prey items, or mating opportunities. Potential negative effects include masking of key environmental sounds or social signals, displacement of fish from their habitat, or interference with sensory orientation and navigation.

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

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[7] By **John R. Christian and R.C. Bocking**, LGL Ltd., environmental research associates (rev. Feb. 2010)

The second transmission pathway between sound source and the inner ear of fishes is via the swim bladder, a gas-filled structure that is much less dense than the rest of the fish's body. The swim bladder, being more compressible and expandable than either water or fish tissue, will differentially contract and expand relative to the rest of the fish in a sound field. The pulsating swim bladder transmits this mechanical disturbance directly to the inner ear (discussed below). Such a secondary source of sound detection may be more or less effective at stimulating the inner ear depending on the amplitude and frequency of the pulsation, and the distance and mechanical coupling between the swim bladder and the inner ear (Popper and Fay 1993).

A recent paper by Popper and Fay (2010) discusses the designation of fishes based on sound detection capabilities. They suggest that the designations 'hearing specialist' and 'hearing generalist' no longer be used for fishes because of their vague and sometimes contradictory definitions, and that there is instead a range of hearing capabilities across species that is more like a continuum, presumably based on the relative contributions of pressure to the overall hearing capabilities of a species.

According to Popper and Fay (2010), one end of this continuum is represented by fishes that only detect particle motion because they lack pressure-sensitive gas bubbles (e.g., swim bladder). These species include elasmobranchs (e.g., sharks) and jawless fishes, and some teleosts including flatfishes. Fishes at this end of the continuum are typically capable of detecting sound frequencies below 1500 Hz.

The other end of the fish hearing continuum is represented by fishes with highly specialized otophysic connections between pressure receptive organs, such as the swim bladder, and the inner ear. These fishes include some squirrelfish, mormyrids, herrings, and otophysan fishes (freshwater fishes with Weberian apparatus, an articulated series of small bones that extend from the swim bladder to the inner ear). Rather than being limited to 1.5 kHz or less in hearing, these fishes can typically hear up to several kHz. One group of fish in the anadromous herring sub-family Alosinae (shads and menhaden) can detect sounds to well over 180 kHz (Mann et al. 1997, 1998, 2001). This may be the widest hearing range of any vertebrate that has been studied to date. While the specific reason for this very high frequency hearing is not totally clear, there is strong evidence that this capability evolved for the detection of the ultrasonic sounds produced by echolocating dolphins to enable the fish to detect, and avoid, predation (Mann et al. 1997; Plachta and Popper 2003).

All other fishes have hearing capabilities that fall somewhere between these two extremes of the continuum. Some have unconnected swim bladders located relatively far from the inner ear (e.g., salmonids, tuna) while others have unconnected swim bladders located relatively close to the inner ear (e.g., Atlantic cod, *Gadus morhua*). There has also been the suggestion that Atlantic cod can detect 38 kHz (Astrup and Møhl 1993). However, the general consensus was that this was not hearing with the ear; probably the fish were responding to exceedingly high pressure signals from the 38-kHz source through some other receptor in the skin, such as touch receptors (Astrup and Møhl 1998).

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

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

2. POTENTIAL EFFECTS ON FISHES

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

2.1 Marine Fishes

Evidence for airgun-induced damage to fish ears has come from studies using pink snapper *Pagrus auratus* (McCauley et al. 2000a,b, 2003). In these experiments, fish were caged and exposed to the sound of a single moving seismic airgun every 10 s over a period of 1 h and 41 min. The source SPL at 1 m was about 223 dB re 1 $\mu Pa \cdot m_{p\text{-}p}$, and the received SPLs ranged from 165 to 209 dB re 1 $\mu Pa_{p\text{-}p}$. The sound energy was highest over the 20–70 Hz frequency range. The pink snapper were exposed to more than 600 airgun discharges during the study. In some individual fish, the sensory epithelium of the inner ear sustained extensive damage as indicated by ablated hair cells. Damage was more extensive in fish examined 58 days post-exposure compared to those examined 18 h post-exposure. There was no evidence of repair or replacement of damaged sensory cells up to 58 days post-exposure. McCauley et al. (2000a,b, 2003) included the following caveats in the study reports: (1) fish were caged and unable to swim away from the seismic source, (2) only one species of fish was examined, (3) the impact on the ultimate survival of the fish is unclear, and (4) airgun exposure specifics required to cause the observed damage were not obtained (i.e., a few high SPL signals or the cumulative effect of many low to moderate SPL signals).

The fish exposed to sound from a single airgun in this study also exhibited startle responses to short range start up and high-level airgun signals (i.e., with received SPLs of 182 to 195 dB re 1 μPa_{rms} (McCauley et al. 2000a,b). Smaller fish were more likely to display a startle response. Responses were observed above received SPLs of 156 to 161 dB re 1 μPa_{rms}. The occurrence of both startle response (classic C-turn response) and alarm responses (e.g., darting movements, flash school expansion, fast swimming) decreased over time. Other observations included downward distributional shift that was restricted by the 10 m x 6 m x 3 m cages, increase in swimming speed, and the formation of denser aggregations. Fish behavior appeared to return to pre-exposure state 15–30 min after cessation of seismic firing.

Pearson et al. (1992) investigated the effects of seismic airgun sound on the behavior of captive rockfishes (*Sebastes* sp.) exposed to the sound of a single stationary airgun at a variety of distances. The airgun used in the study had a source SPL at 1 m of 223 dB re 1 $\mu Pa \cdot m_{0\text{-}p}$, and measured received SPLs ranged from 137 to 206 dB re 1 $\mu Pa_{0\text{-}p}$. The authors reported that rockfishes reacted to the airgun sounds by exhibiting varying degrees of startle and alarm responses, depending on the species of rockfish and the received SPL. Startle responses were observed at a minimum received SPL of 200 dB re 1 $\mu Pa_{0\text{-}p}$, and alarm responses occurred at a minimum received SPL of 177 dB re 1 $\mu Pa_{0\text{-}p}$. Other observed behavioral changes included the tightening of schools, downward distributional shift, and random movement and orientation. Some fishes ascended in the water column and commenced to mill (i.e., “eddy”) at increased speed, while others descended to the bottom of the enclosure and remained motionless. Pre-exposure behavior was reestablished from 20 to 60 min after cessation of seismic airgun discharge. Pearson et al. (1992) concluded that received SPL thresholds for overt rockfish behavioral response and more subtle rockfish behavioral response are 180 dB re 1 µPa$_{0\text{-p}}$ and 161 dB re 1 µPa$_{0\text{-p}}$, respectively.

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

In another study, caged European sea bass (*Dicentrarchus labrax*) were exposed to multiple discharges from a moving seismic airgun array with a source SPL of about 256 dB re 1 µPa·m $_{0\text{-p}}$ (unspecified measure type) (Santulli et al. 1999). The airguns were discharged every 25 s during a 2-h period. The minimum distance between fish and seismic source was 180 m. The authors did not indicate any observed pathological injury to the sea bass. Blood was collected from both exposed fish (6 h post-exposure) and control fish (6 h pre-exposure) and subsequently analyzed for cortisol, glucose, and lactate levels. Levels of cortisol, glucose, and lactate were significantly higher in the sera of exposed fish compared to sera of control fish. The elevated levels of all three chemicals returned to pre-exposure levels within 72 h of exposure (Santulli et al. 1999).

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

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

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

Hassel et al. (2003, 2004) studied the potential effects of exposure to airgun sound on the behavior of captive lesser sandeel, *Ammodytes marinus*. Depth of the study enclosure used to hold the sandeel was about 55 m. The moving airgun array had an estimated source SPL of 256 dB re 1 µPa·m (unspecified measure type). Received SPLs were not measured. Exposures were conducted over a 3-day period in a 10 km × 10 km area with the cage at its center. The distance between airgun array and fish cage ranged from 55 m when the array was overhead to 7.5 km. No mortality attributable to exposure to the airgun sound was noted. Behavior of the fish was monitored using underwater video cameras, echo sounders, and commercial fishery data collected close to the study area. The approach of the seismic vessel appeared to cause an increase in tail-beat frequency although the sandeels still appeared to swim calmly. During seismic airgun discharge, many fish exhibited startle responses, followed by flight from the immediate area. The frequency of occurrence of startle response seemed to increase as the operating seismic array moved closer to the fish. The sandeels stopped exhibiting the startle response once the airgun discharge ceased. The sandeel tended to remain higher in the water column during the airgun discharge, and none of them were observed burying themselves in the soft substrate. The commercial fishery catch data were inconclusive with respect to behavioral effects.

Various species of demersal fishes, blue whiting, and some small pelagic fishes were exposed to a moving seismic airgun array with a source SPL of about 250 dB re 1 µPa·m (unspecified measure type) (Dalen and Knutsen 1986). Received SPLs estimated using the assumption of spherical spreading ranged from 200 to 210 dB re 1 µPa (unspecified measure type). Seismic sound exposures were conducted every 10 s during a one week period. The authors used echo sounders and sonars to assess the pre- and post-exposure fish distributions. The acoustic mapping results indicated a significant decrease in abundance of demersal fish (36%) after airgun discharge but comparative trawl catches did not support this. Non-significant reductions in the abundances of blue whiting and small pelagic fish were also indicated by post-exposure acoustic mapping.

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

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

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

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

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

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

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

2.2 Freshwater Fishes

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

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

2.3 Anadromous Fishes

In uncontrolled experiments using a very small sample of different groups of young salmonids, including Arctic cisco, fish were caged and exposed to various types of sound. One sound type was either a single firing or a series of four firings 10 to 15 s apart of a 300-in^3 seismic airgun at 2000 to 2200 psi (Falk and Lawrence 1973). Swim bladder damage was reported but no mortality was observed when fish were exposed within 1 to 2 m of an airgun source with source level, as estimated by Turnpenny and Nedwell (1994), of ~230 dB re 1 µPa·m (unspecified measure).

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

Weinhold and Weaver (1972, cited in Turnpenny et al. 1994) exposed caged coho salmon smolts to impulses from 330 and 660-in^3 airguns at distances ranging from 1 to 10 m, resulting in received levels estimated at ~214 to 216 dB (units not given). No lethal effects were observed.

It should be noted that, in a recent and comprehensive review, Hastings and Popper (2005) take issue with many of the authors cited above for problems with experimental design and execution, measurements, and interpretation. Hastings and Popper (2005) deal primarily with possible effects of pile-driving sounds (which, like airgun sounds, are impulsive and repetitive). However, that review provides an excellent and critical review of the impacts to fish from other underwater anthropogenic sounds.

3. INDIRECT EFFECTS ON FISHERIES

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

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

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

Turnpenny and Nedwell (1994) also reported on the effects of seismic airgun discharge on inshore bass fisheries in shallow U.K. waters (5 to 30 m deep). The airgun array used had a source level of 250 dB re 1 µPa·m$_{\text{0-p}}$. Received levels in the fishing areas were estimated to be 163–191 dB re 1 µPa$_{\text{0-p}}$. Using fish tagging and catch record methodologies, they concluded that there was not any distinguishable migration from the ensonified area, nor was there any reduction in bass catches on days when seismic airguns were discharged. The authors concluded that effects on fisheries would be smaller in shallow nearshore waters than in deep water because attenuation of sound is more rapid in shallow water.

Skalski et al. (1992) used a 100-in^3 airgun with a source level of 223 dB re 1 µPa·m$_{\text{0-p}}$ to examine the potential effects of airgun sound on the catchability of rockfishes. The moving airgun was discharged along transects in the study fishing area, after which a fishing vessel deployed a set line, ran three echo sounder transects, and then deployed two more set lines. Each fishing experiment lasted 1 h 25 min. Received SPLs at the base of the rockfish aggregations ranged from 186 to 191 dB re 1 µPa$_{\text{0-p}}$. The catch-per-unit-effort (CPUE) for rockfish declined on average by 52.4% when the airguns were operating. Skalski et al. (1992) believed that the reduction in catch resulted from a change in behavior of the fishes. The fish schools descended towards the bottom and their swimming behavior changed during airgun discharge. Although fish dispersal was not observed, the authors hypothesized that it could have occurred at a different location with a different bottom type. Skalski et al. (1992) did not continue fishing after cessation of airgun discharge. They speculated that CPUE would quickly return to normal in the experimental area, because fish behavior appeared to normalize within minutes of cessation of airgun discharge. However, in an area where exposure to airgun sound might have caused the fish to disperse, the authors suggested that a lower CPUE might persist for a longer period.

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

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APPENDIX F:

REVIEW OF THE EFFECTS OF AIRGUN SOUNDS ON MARINE INVERTEBRATES[8]

This review provides a detailed summary of the limited data and available literature on the observed effects (or lack of effects) of exposure to airgun sound on marine invertebrates. Specific conditions and results of the studies, including sound exposure levels and sound thresholds of responses, are discussed when available.

Sound caused by underwater seismic survey equipment results in energy pulses with very high peak pressures (Richardson et al. 1995). This was especially true when chemical explosives were used for underwater surveys. Virtually all underwater seismic surveying conducted today uses airguns which typically have lower peak pressures and longer rise times than chemical explosives. However, sound levels from underwater airgun discharges might still be high enough to potentially injure or kill animals located close to the source. Also, there is a potential for disturbance to normal behavior upon exposure to airgun sound. The following sections provide an overview of sound production and detection in marine invertebrates, and information on the effects of exposure to sound on marine invertebrates, with an emphasis on seismic survey sound. In addition, Fisheries and Oceans Canada has published two internal documents that provide a literature review of the effects of seismic and other underwater sound on invertebrates (Moriyasu et al. 2004; Payne et al. 2008). The available information as reviewed in those documents and here includes results of studies of varying degrees of scientific rigor as well as anecdotal information.

SOUND PRODUCTION

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

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

While feeding, king crab *Paralithodes camtschaticus* produce impulsive sounds that appear to stimulate movement by other crabs, including approach behavior (Tolstoganova 2002). King crab also

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[8] By **John R. Christian**, LGL Ltd., environmental research associates (revised Nov. 2009).

appeared to produce 'discomfort' sounds when environmental conditions were manipulated. These discomfort sounds differ from the feeding sounds in terms of frequency range and pulse duration.

Snapping shrimp *Synalpheus parneomeris* are among the major sources of biological sound in temperate and tropical shallow-water areas (Au and Banks 1998). By rapidly closing one of its frontal chelae (claws), a snapping shrimp generates a forward jet of water and the cavitation of fast moving water produces a sound. Both the sound and the jet of water may function in feeding and territorial behaviors of alpheidae shrimp. Measured source sound pressure levels (SPLs) for snapping ship were 183–189 dB re 1 µPa · m_{p-p} and extended over a frequency range of 2–200 kHz.

SOUND DETECTION

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

More is known about the acoustic detection capabilities in decapod crustaceans than in any other marine invertebrate group, although cephalopod acoustic capabilities are now becoming a focus of study. Crustaceans appear to be most sensitive to sounds of low frequencies, i.e., <1000 Hz (Budelmann 1992; Popper et al. 2001). A study by Lovell et al. (2005) suggests greater sensitivity of the prawn *Palaemon serratus* to low-frequency sound than previously thought. Lovell et al. (2006) showed that *P. serratus* is capable of detecting a 500 Hz tone regardless of the prawn's body size and the related number and size of statocyst hair cells. Studies of American lobsters suggest that these crustaceans are more sensitive to higher frequency sounds than previously realized (Pye and Watson III 2004).

It is possible that statocyst hair cells of cephalopods are directionally sensitive in a way that is similar to the responses of hair cells of the vertebrate vestibular and lateral line systems (Budelmann and Williamson 1994; Budelmann 1996). Kaifu et al. (2008) provided evidence that the cephalopod *Octopus ocellatus* detects particle motion with its statocyst. Studies by Packard et al. (1990), Rawizza (1995) and Komak et al. (2005) have tested the sensitivities of various cephalopods to water-borne vibrations, some of which were generated by low-frequency sound. Using the auditory brainstem response (ABR) approach, Hu et al. (2009) showed that auditory evoked potentials can be obtained in the frequency ranges 400 to 1500 Hz for the squid *Sepiotheutis lessoniana* and 400 to 1000 Hz for the octopus *Octopus vulgaris*, higher than frequencies previously observed to be detectable by cephalopods.

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

POTENTIAL SEISMIC EFFECTS

In marine invertebrates, potential effects of exposure to sound can be categorized as pathological, physiological, and behavioral. Pathological effects include lethal and sub-lethal injury to the animals, physiological effects include temporary primary and secondary stress responses, and behavioral effects refer to changes in exhibited behaviors (i.e., disturbance). The three categories should not be considered as independent of one another and are likely interrelated in complex ways.

***Pathological Effects*.—**In water, acute injury or death of organisms as a result of exposure to sound appears to depend on two features of the sound source: (1) the received peak pressure, and (2) the time required for the pressure to rise and decay. Generally, the higher the received pressure and the less time it takes for the pressure to rise and decay, the greater the chance of acute pathological effects. Considering the peak pressure and rise/decay time characteristics of seismic airgun arrays used today, the associated pathological zone for invertebrates would be expected to be small (i.e., within a few meters of the seismic source, at most). Few studies have assessed the potential for pathological effects on invertebrates from exposure to seismic sound.

The pathological impacts of seismic survey sound on marine invertebrates were investigated in a pilot study on snow crabs *Chionoecetes opilio* (Christian et al. 2003, 2004). Under controlled field experimental conditions, captive adult male snow crabs, egg-carrying female snow crabs, and fertilized snow crab eggs were exposed to variable SPLs (191–221 dB re 1 $\mu Pa_{0\text{-}p}$) and sound energy levels (SELs) (<130–187 dB re 1 $\mu Pa^2 \cdot s$). Neither acute nor chronic (12 weeks post-exposure) mortality was observed for the adult crabs. However, a significant difference in development rate was noted between the exposed and unexposed fertilized eggs/embryos. The egg mass exposed to seismic energy had a higher proportion of less-developed eggs than did the unexposed mass. It should be noted that both egg masses came from a single female and any measure of natural variability was unattainable (Christian et al. 2003, 2004).

In 2003, a collaborative study was conducted in the southern Gulf of St. Lawrence, Canada, to investigate the effects of exposure to sound from a commercial seismic survey on egg-bearing female snow crabs (DFO 2004). This study had design problems that impacted interpretation of some of the results (Chadwick 2004). Caged animals were placed on the ocean bottom at a location within the survey area and at a location outside of the survey area. The maximum received SPL was ~195 dB re 1 $\mu Pa_{0\text{-}p}$. The crabs were exposed for 132 hr of the survey, equivalent to thousands of seismic shots of varying received SPLs. The animals were retrieved and transferred to laboratories for analyses. Neither acute nor chronic lethal or sub-lethal injury to the female crabs or crab embryos was indicated. DFO (2004) reported that some exposed individuals had short-term soiling of gills, antennules and statocysts, bruising of the hepatopancreas and ovary, and detached outer membranes of oocytes. However, these differences could not be linked conclusively to exposure to seismic survey sound. Boudreau et al. (2009) presented the proceedings of a workshop held to evaluate the results of additional studies conducted to answer some questions arising from the original study discussed in DFO (2004). Proceedings of the workshop did not include any more definitive conclusions regarding the original results.

Payne et al. (2007) recently conducted a pilot study of the effects of exposure to airgun sound on various health endpoints of the American lobster. Adult lobsters were exposed either 20 to 200 times to 202 dB re 1$\mu Pa_{p\text{-}p}$ or 50 times to 227 dB re 1$\mu Pa_{p\text{-}p}$, and then monitored for changes in survival, food consumption, turnover rate, serum protein level, serum enzyme levels, and serum calcium level. Observations extended over a period of a few days to several months. Results showed no delayed mortality or damage to the mechanosensory systems associated with animal equilibrium and posture (as assessed by turnover rate).

In a field study, Pearson et al. (1994) exposed Stage II larvae of the Dungeness crab *Cancer magister* to single discharges from a seven-airgun array and compared their mortality and development rates with those of unexposed larvae. No statistically significant differences were found in immediate survival, long-term survival, or time to molt between the exposed and unexposed larvae, even those exposed within 1 m of the seismic source.

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

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

***Physiological Effects*.—**Biochemical responses by marine invertebrates to acoustic exposure have also been studied to a limited degree. Such studies of stress responses could possibly provide some indication of the physiological consequences of acoustic exposure and perhaps any subsequent chronic detrimental effects. Stress responses could potentially affect animal populations by reducing reproductive capacity and adult abundance.

Stress indicators in the haemolymph of adult male snow crabs were monitored immediately after exposure of the animals to seismic survey sound (Christian et al. 2003, 2004) and at various intervals after exposure. No significant acute or chronic differences were found between exposed and unexposed animals in which various stress indicators (e.g., proteins, enzymes, cell type count) were measured.

Payne et al. (2007), in their study of the effects of exposure of adult American lobsters to airgun sound, noted decreases in the levels of serum protein, particular serum enzymes and serum calcium, in the haemolymph of animals exposed to the sound pulses. Statistically significant differences (P=0.05) were noted in serum protein at 12 days post-exposure, serum enzymes at 5 days post-exposure, and serum calcium at 12 days post-exposure. During the histological analysis conducted 4 months post-exposure, Payne et al. (2007) noted more deposits of PAS-stained material, likely glycogen, in the hepatopancreas of some of the exposed lobsters. Accumulation of glycogen could be due to stress or disturbance of cellular processes.

Price (2007) found that blue mussels *Mytilus edulis* responded to a 10 kHz pure tone continuous signal by decreasing respiration. Smaller mussels did not appear to react until exposed for 30 min whereas larger mussels responded after 10 min of exposure. The oxygen uptake rate tended to be reduced to a greater degree in the larger mussels than in the smaller animals.

In general, the limited studies done to date on the effects of acoustic exposure on marine invertebrates have not demonstrated any serious pathological and physiological effects.

***Behavioral Effects*.—**Some recent studies have focused on potential behavioral effects on marine invertebrates.

Christian et al. (2003) investigated the behavioral effects of exposure to airgun sound on snow crabs. Eight animals were equipped with ultrasonic tags, released, and monitored for multiple days prior to exposure and after exposure. Received SPL and SEL were ~191 dB re 1 µ$Pa_{0\text{-}p}$ and <130 dB re 1 µPa^2·s, respectively. The crabs were exposed to 200 discharges over a 33-min period. None of the tagged animals left the immediate area after exposure to the seismic survey sound. Five animals were captured in the snow crab commercial fishery the following year, one at the release location, one 35 km from the release location, and three at intermediate distances from the release location.

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

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

Parry and Gason (2006) statistically analyzed data related to rock lobster *Jasus edwardsii* commercial catches and seismic surveying in Australian waters from 1978 to 2004. They did not find any evidence that lobster catch rates were affected by seismic surveys.

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

Payne et al. (2007), in their study of the effects of exposure to airgun sound on adult American lobsters, noted a trend for increased food consumption by the animals exposed to seismic sound.

Andriguetto-Filho et al. (2005) attempted to evaluate the impact of seismic survey sound on artisanal shrimp fisheries off Brazil. Bottom trawl yields were measured before and after multiple-day shooting of an airgun array. Water depth in the experimental area ranged between 2 and 15 m. Results of the study did not indicate any significant deleterious impact on shrimp catches. Anecdotal information from Newfoundland, Canada, indicated that catch rates of snow crabs showed a significant reduction immediately following a pass by a seismic survey vessel (G. Chidley, Newfoundland fisherman, pers. comm.). Additional anecdotal information from Newfoundland indicated that a school of shrimp observed via a fishing vessel sounder shifted downwards and away from a nearby seismic airgun sound source (H. Thorne, Newfoundland fisherman, pers. comm.). This observed effect was temporary.

Caged brown shrimp *Crangon crangon* reared under different acoustical conditions exhibited differences in aggressive behavior and feeding rate (Lagardère 1982). Those exposed to a continuous sound source showed more aggression and less feeding behavior. It should be noted that behavioral responses by caged animals may differ from behavioral responses of animals in the wild.

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

Komak et al. (2005) also reported the results of a study of cephalopod behavioral responses to local water movements. In this case, juvenile cuttlefish *Sepia officinalis* exhibited various behavioral responses to local sinusoidal water movements of different frequencies between 0.01 and 1000 Hz. These responses included body pattern changing, movement, burrowing, reorientation, and swimming. Similarly, the behavioral responses of the octopus *Octopus ocellatus* to non-impulse sound have been investigated by Kaifu et al. (2007). The sound stimuli, reported as having levels 120 dB re 1 μPa rms, were at various frequencies: 50, 100, 150, 200 and 1000 Hz. The respiratory activity of the octopus changed when exposed to sound in the 50–150 Hz range but not for sound at 200–1,000 Hz. Respiratory suppression by the octopus might have represented a means of escaping detection by a predator.

Low-frequency sound (<200 Hz) has also been used as a means of preventing settling/fouling by aquatic invertebrates such as zebra mussels *Dreissena polymorpha* (Donskoy and Ludyanskiy 1995) and balanoid barnacles *Balanus* sp. (Branscomb and Rittschof 1984). Price (2007) observed that blue mussels *Mytilus edulis* closed their valves upon exposure to 10 kHz pure tone continuous sound.

Although not demonstrated in the invertebrate literature, masking can be considered a potential effect of anthropogenic underwater sound on marine invertebrates. Some invertebrates are known to produce sounds (Au and Banks 1998; Tolstoganova 2002; Latha et al. 2005). The functionality and biological relevance of these sounds are not understood (Jeffs et al. 2003, 2005; Lovell et al. 2005; Radford et al. 2007). If some of the sounds are of biological significance to some invertebrates, then masking of those sounds or of sounds produced by predators, at least the particle displacement component, could potentially have adverse effects on marine invertebrates. However, even if masking does occur in some invertebrates, the intermittent nature of airgun sound is expected to result in less masking effect than would occur with continuous sound.

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