REQUEST FOR AN INCIDENTAL HARASSMENT AUTHORIZATION BY STATOIL TO ALLOW INCIDENTAL HARASSMENT OF MARINE MAMMALS DURING A 3D MARINE SEISMIC SURVEY IN THE CHUKCHI SEA, ALASKA, 2010

submitted by

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to

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18 December 2009
Revised 14 April 2010

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SUMMARY

Statoil plans to conduct a 3D marine seismic survey in the Chukchi Sea during the open water season of 2010. This survey will use two towed airgun array consisting of 26 active (10 spare) airguns with a maximum discharge volume of 3000 cubic inch (in^3). The proposed 3D survey will take place in a 915 mi^2 (2,370 km^2) survey area ~150 mi (241 km) west of Barrow in water depth of ~100–165 ft (30–50 m). The seismic survey is designed to collect 3D data of the deep sub-surface in Statoil's Chukchi leases in support of future oil and gas development within the area of coverage. The data will help identify source rocks, migration pathways, and play types. In addition, a 2D tie line survey has been designed as a second priority program to acquire useful information in the region. The four stand alone 2D lines (with a total length of ~ 420 mi or 675 km) are designed to tie the details of the new high resolution 3D image to the surrounding regional geology to facilitate interpretation of more regional trends. The number of 2D km acquired will to some degree be dependent on the 2010 season's restrictive ice coverage and the 3D data acquisition progress. Statoil requests that it be issued an Incidental Harassment Authorization (IHA) allowing non-lethal harassment of marine mammals for their Chukchi lease area including the indicated 2D lines that might or might not be acquired dependent on the 2010 seasonal ice coverage. This request is submitted pursuant to Section 101 (a) (5) (D) of the Marine Mammal Protection Act (MMPA), 16 U.S.C. §1371 (a) (5).

Nine species of cetaceans are known to occur in the Chukchi Sea. Three species (bowhead, fin, and humpback whales) are listed as endangered under the ESA. Four of the nine species (bowhead, beluga, and gray whales, and harbor porpoise) are likely to be encountered during the proposed survey activities. The other five cetacean species could occur in the Chukchi Sea, but each of these species is rare or extralimital and unlikely to be encountered in the proposed survey area. In addition, four pinniped species (not including Pacific walrus) may be encountered in the Chukchi Sea. Statoil is proposing a marine mammal monitoring and mitigation program to minimize the impacts of the proposed activity on marine mammals during the proposed 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, the marine mammals occurring in the study area, proposed measures to mitigate against any potential injurious effects on marine mammals, and a plan to monitor behavioral effects of marine mammals from the planned seismic survey. A Letter of Authorization will be submitted separately to the U.S. Fish & Wildlife Service with regard to potential effects on species managed by USFWS – the walrus and polar bear.

I. OPERATIONS TO BE CONDUCTED

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

Statoil plans to conduct geophysical data acquisition activities in the Chukchi Sea in the period 15 July through 30 November 2010. Data acquisition is expected to take ~60 days (including anticipated downtime), but the total period for this request is from 15 July through 30 November to allow for unexpected downtime. The project area encompasses ~915 mi^2 (2,370 km^2) in Statoil lease holdings in the MMS OCS Lease Sale 193 area in the northern Chukchi Sea (Figure 1). The activities consist of 3D seismic data acquisition and a 2D tie line survey as a second priority program. This section provides details about the operations to be conducted and Section 2 summarizes details on the project area, survey period and duration.

1. PURPOSE

Statoil acquired 16 leases in the Chukchi Sea during Lease Sale 193 held in February 2008. The lease areas in which the proposed 3D seismic survey is planned are located ~150 mi (240 km) west of Barrow and ~100 mi (160 km) northwest of Wainwright. The four 2D seismic tracklines run through that same area to four different well sites with known geological information. All planned geophysical data acquisition activities will be conducted by Statoil's seismic contractor, Fugro Geoteam, Inc.

The purpose of the proposed 3D seismic survey is to collect seismic reflection data that reveal the sub-bottom profile for assessments of petroleum reserves in the area. Ultra-deep 3D lines such as those to be collected, will be used to better evaluate the evolution of the petroleum system at the basin level, including identifying source rocks, migration pathways, and play types. A 2D tie line survey has been designed as a second priority program to allow the vessel to acquire useful information in the region. The main goal of the 2D lines is to acquire information that allows to tie-in the details of the new high resolution 3D image to known surrounding regional geology.

2. VESSEL MOVEMENTS

The proposed survey will take place offshore in the Chukchi Sea. The vessels involved in the seismic survey activities will consist of at least three vessels as listed below. Specifications of these vessels (or equivalent vessels if availability changes) are provided in Appendix A.

- One (1) seismic source vessel, the M/V *Geo Celtic* or similar equipped vessel, to tow the two 3000 in^3 airgun arrays and hydrophone streamer for the 3D (and 2D) seismic data acquisition and to serve as a platform for marine mammal monitoring;
- One (1) chase/monitoring vessel, the M/V *Gulf Provider* or similar equipped vessel, for marine mammal monitoring, crew transfer, support and supply duties.
- One (1) chase/monitoring vessel, the M/V *Thor Alpha* or similar equipped vessel, for marine mammal monitoring, support and supply duties.

Sound source verification measurements will be conducted from one of the chase/monitoring vessels.

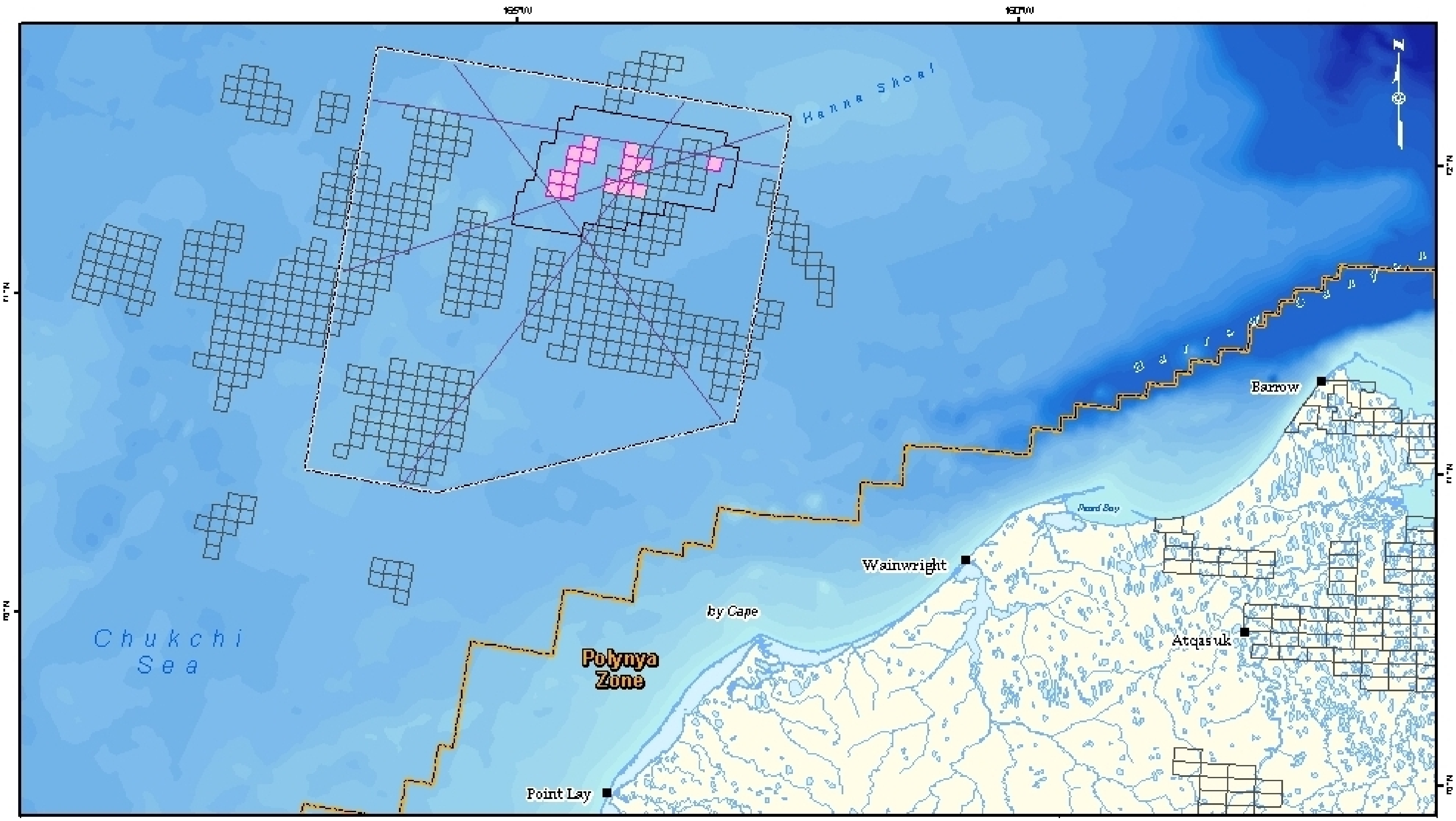

FIGURE 1. Location of the 3D seismic survey area (black outline) and 2D tracklines (purple lines). **The dotted line represents** the permit area and encompasses all 2D tracklines and the 3D survey area. The boundary of the polynya is shown by the orange line. Map prepared for by ASRC Energy Services.

Depending on ice conditions, the seismic vessel M/V *Geo Celtic*, and the two chase/monitoring vessel M/V *Thor Alpha* and M/V *Gulf Provider* will mobilize from Dutch Harbor and travel to the Chukchi Sea survey area ~mid/end July. The anticipated transit time is ~5 days (weather depending). Directly upon arrival in the survey area, depending on ice conditions, the M/V *Geo Celtic* will deploy the airgun array and start operating their guns for the purpose of sound source verification measurements. An environmental awareness training program is planned prior to travel to the project site, in order to make the participating vessels with its entire crew, aware of the environmental sensitivity and the general and specific regulation applicable to this survey.

The M/V *Geo Celtic*, and chase/monitoring vessels will be self-contained and the crew will live aboard the vessels. Crew changes are planned to be conducted with one of the chase/monitoring vessels at least once during the survey. Nome will be the principal port for resupply, refueling, and crew changes. However, it is possible that under certain circumstances these activities might have to be conducted through Barrow or Wainwright. Emergencies will be covered by a search and rescue (SAR) helicopter stationed in Barrow. The M/V *Geo Celtic* will serve as the platform from which vessel-based marine mammal observers will watch for marine mammals during the transit to the survey area, airgun operations, and transit to the demobilization port. Two chase/monitoring vessels will be used to protect the streamer from damage, for supply and support and for monitoring activities as required. All chase/monitoring vessels will have MMOs onboard and will assist with the implementation of mitigation measures as described in Section XI. Chase/monitoring vessels will not be introducing sounds into the water beyond those associated with normal vessel operations.

3. SURVEY DETAILS

The entire 3D program, if it can be completed, will consist of ~3,100 mi (4,990 km) of production line, not including line turns. Water depth within the study area is ~100–165 ft (30–50 m). The 3D seismic data acquisition will be conducted from the M/V *Geo Celtic*. The M/V *Geo Celtic* will tow two identical airgun arrays at ~20 ft (6 m) depth and at a distance of ~902 ft (275 m) behind the vessel. Each array is composed of three strings for a total of 26 active G-guns (4×60 in^3, 8×70 in^3, 6×100 in^3, 4×150 in^3, and 4×250 in^3) with a total discharge volume of 3000 in^3. Each array also consists of 5 clusters of 10 inactive airguns that will be used as spares. One of the smallest guns in the array (60 in^3) will be used as the mitigation gun. More details of the airgun array and its components are described in Appendix B. In addition to the airgun array, pinger systems (ION Digirange II, or similar systems) will be used to position the streamer array relative to the vessel.

The vessel will travel along pre-determined lines at a speed of ~4–5 knots while one of the airgun arrays discharges every ~8-10 seconds (shot interval ~61.52 ft [18.75 m]). The streamer hydrophone array will consist of twelve streamers of up to ~2.2 mi (4 km) in length, with a total of 20,000-25,000 hydrophones at 6.6 ft (2 m) spacing. This large hydrophone streamer receiver array, designed to maximize efficiency and minimize the number of source points, will receive the reflected signals from the airgun array and transfer the data to an on-board processing system.

A 2D tie line survey has been designed as a second priority program to allow the vessel to acquire useful information in the region. The four stand alone 2D lines have a total length of ~ 420 mi (675 km) and are designed to tie the details of the new high resolution 3D image to known surrounding regional geology (Figure 1).

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 primary interest of the proposed seismic survey is to obtain more details of the geologic subsurface formations of the 16 Statoil Chukchi leases (Figure 1). To achieve full data coverage in the 3D survey area of interest a larger zone needs to be surveyed to account for accurate migration of acoustic reflections. The size of the 3D survey area has been reduced to an absolute minimum and covers 915 mi^2 or 2,370 km^2. The approximate boundaries of the total surface area are between 71° 30' N and 72° 00' N and between 165° W and 162° 30' W. The water depth in the survey area varies from 100 to 165 ft (30 to 50 m). A total of four 2D well tie lines with a total length of ~420 mi (675 km) are included in the survey plan as a second priority program.

The M/V *Geo Celtic*, or similar vessel, will arrive in Dutch Harbor ~mid July 2010. The vessels will be resupplied and the crew changed at this port. Depending on ice conditions, all three vessels will depart Dutch Harbor around mid/end July with an expected transit time of ~5 days (weather depending). Directly upon arrival in the 3D survey area, depending on ice conditions, the M/V *Geo Celtic* will deploy the airgun array and start operating their guns for the purpose of sound source verification measurements (see Section XI and XIII for more details). The startup date of seismic data acquisition is expected to be early/mid August but depends on local ice conditions.

Upon completion of these measurements the seismic data acquisition in the Chukchi Sea will start and, depending on the start date, is expected to be completed in the first half of October. This is based on an estimated duration of 60 days from first to last shotpoint (including anticipated downtime). The data acquisition is a 24-hour operation.

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 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 1). Three cetacean species, the bowhead, humpback and fin whales, are listed as *Endangered* under the ESA. The bowhead whale is more common in the survey area than the other two endangered species. Fin whale sightings are uncommon and this species is therefore unlikely to be encountered in the proposed survey area in the Chukchi Sea. Humpback whales are also uncommon in the Chukchi Sea. Most recent records include three humpback sightings during a vessel-based survey in the Chukchi Sea in 2007 and one sighting in 2008 (Haley et al. 2009a). Three other cetacean species (minke whale, killer whale and narwhal) and one pinniped species (ribbon seal) could occur in the area but are rare or extralimital in the Chukchi Sea. Based on the foregoing, the marine mammal species under NMFS jurisdiction most likely to occur in the seismic survey area include four cetacean species (beluga, bowhead, and gray whales, and harbor porpoise), and three pinniped species (ringed, bearded, and spotted seals).

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 four cetacean species (beluga, bowhead, and gray whales, and harbor porpoise), and three pinniped species (ringed, bearded, and spotted seals). Most encounters are likely to occur in nearshore shelf habitats or along the ice edge. Of all species, the ringed seal is most widely distributed (in space and time) and therefore most likely to be encountered during the proposed seismic survey activities. Encounters with other species, such as bowhead and gray whales are expected to be limited to particular regions and seasons, as discussed below.

Five additional cetacean species—the narwhal, killer whale, minke whale, humpback whale, and fin whale—could occur in the project area, but each of these species is uncommon or rare in the Chukchi Sea and relatively few encounters with these species are expected during the seismic program. The narwhal occurs in Canadian waters and occasionally in the Beaufort Sea, but is rare there and not expected to be encountered at all in the Chukchi Sea.

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

Species	**Abundance**	**Habitat**	**ESA**[1]	**IUCN**[2]	**CITES**[3]
		Odontocetes			
Beluga whale*(Delphinapterus leucas)*					
Beaufort Sea stock Eastern Chukchi Sea stock	39,258[4] 3,710[5]	Offshore, Coastal, Ice edges	Not listed	NT	II
Narwhal (*Monodon monoceros*)	Rare[6]	Offshore, Ice edge	Not listed	NT	II
Killer whale *(Orcinus orca)*	Rare	Widely distributed	Not listed	DD	II
Harbor Porpoise *(Phocoena phocoena)*					
Bering Sea stock	48,215[5]	Coastal, inland waters, shallow offshore waters	Not listed	LC	II

TABLE 1. Continued.

		Mysticetes			
Bowhead whale *(Balaena mysticetus)*					
Bering-Chukchi-Beaufort stock	11,800[7]	Pack ice & coastal	Endangered	LR-cd	I
Gray whale (*Eschrichtius robustus*)					
eastern Pacific population	488[8] 20,110[9]	Coastal, lagoons	Not listed	LC	I
Minke whale (*Balaenoptera acutorostrata*)	Small numbers	Shelf, coastal	Not listed	LC	I
Fin whale (*Balaenoptera physalus*)	Rare in Chukchi	Slope, mostly pelagic	Endangered	EN	I
Humpback whale (*Megaptera novaeangliae*)					
North Pacific population	Rare	Shelf, coastal	Endangered	LC	I
		Pinnipeds			
Bearded seal (*Erignathus barbatus*)					
Alaska population	250,000 - 300,000[10]	Pack ice, open water	In review for listing	LC	–
Eastern Chukchi Sea population	4,863[11]				
Spotted seal (*Phoca largha*)	~59,214[12] 101,568[13]	Pack ice, open water, coastal haulouts	Not listed	DD	–
Ringed seal (*Phoca hispida*)					
Bering/Chukchi Sea stock	230,673[14]	Landfast & pack ice, open water	In review for listing	LC	–
Beaufort Sea stock	326,500[15]				
Ribbon seal (*Histriophoca fasciata*)	90-100,000[16]	Pack ice, open water	Not listed	DD	–

[1] U.S. Endangered Species Act.

[2] IUCN 2009. IUCN Red List of Threatened Species. Version 2009.2. <www.iucnredlist.org>. Codes for IUCN classifications: EN = Endangered; LR = Lower Risk (-cd = conservation dependent); NT = Near Threatened; LC = Least Concern; DD = Data Deficient. Category descriptions can be found at http://www.iucnredlist.org/apps/redlist/static/categories_criteria_3_1#categories

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

[4] IWC 2000, Angliss and Allen 2009

[5] Angliss and Allen 2009

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

[7] 2004 Population estimate from photo-identification data (Koski et al. 2009).

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

[9] North Pacific gray whale population (Rugh 2003 *in* Keller and Gerber 2004); see also Rugh et al. (2005).

[10] Bering-Chukchi Sea population (Angliss and Allen 2009).

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

[12] Alaskan population (Rugh et al. 1995, cited in Angliss and Allen 2009).

[13] Eastern and Central Bering Sea (Boveng et al. 2009).

[14] Average Bering/Chukchi Sea population (Bengtson et al. 2005)

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

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

1. ODONTOCETES (TOOTHED WHALES)

Beluga (Delphinapterus leucas)

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

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 underestimate of the true population size. A possible population increase since 1992 has also not been included in this estimate. 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). Moore (2000) and Moore et al. (2000b) suggested that beluga whales select deeper slope water independent of ice cover. However, during the westward migration in late summer and autumn, small numbers of belugas are sometimes seen near the north coast of Alaska (e.g., Johnson 1979). Lyons et al. (2008) reported higher beluga sighting rates at locations >37.3 mi (60 km) offshore than at locations nearer shore during aerial surveys in the Alaskan Beaufort Sea in 2006 and 2007. The main fall migration corridor of beluga whales is ~62+ mi (100 km) north of the coast. Satellite-linked telemetry data show that some belugas of this population migrate west considerably farther offshore, as far north as 76º to 78ºN latitude (Richard et al. 1997, 2001).

The ***eastern Chukchi Sea*** population is estimated at 3,710 animals (Angliss and Allen 2009). This estimate was based on surveys conducted in 1989–1991. Survey effort was concentrated on the 106 mi (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 684 ft (1,100 km) offshore between Barrow and the Mackenzie River delta spending time in water with 90% ice coverage.

During aerial surveys in nearshore areas (i.e., ~23 mi [37 km] offshore) of the Chukchi Sea in July–November 2006 and 2007, and July–October 2008, peak beluga sighting rates were recorded in July and the lowest monthly sighting rates were recorded in August and September (Thomas et al. 2009). Beluga sighting rates and number of individuals were generally highest in waters 16–22 mi (25–35 km) offshore. The largest single groups, however, were sighted at locations within 3 mi (5 km) from shore.

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.

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

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. Richard et al. (in press) estimated the population size of narwhals in the Canadian High Arctic at ~60,000. There are scattered records of narwhal in Alaskan waters where the species is considered extralimital (Reeves et al. 2002). Thus, although theoretically possible, it is very unlikely that narwhals would be encountered in the Chukchi Sea.

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 497 mi (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 2008 (Haley et al. 2009b). MMOs onboard industry vessels did not record any killer whale sighting in the Beaufort Sea in 2006–2008 (Savarese 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 722 ft (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).

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

Although separate harbor porpoise stocks for Alaska have not been identified, Alaskan harbor porpoises have been divided into three groups for management purposes. These groups include animals from southeast Alaska, Gulf of Alaska, and Bering Sea populations. Chukchi Sea harbor porpoises belong to the Bering Sea group which includes animals from Unimak Pass northward. Based on aerial surveys in 1999, the Bering Sea population was estimated at 48,215 animals, although this estimate is likely conservative as the surveyed area did not include known harbor porpoise range near the Pribilof Islands or waters north of Cape 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 commonly encountered throughout the Chukchi Sea in 2006–2008 (Haley et al. 2009b; Ireland et al. 2008). Based on recent surveys the harbor porpoise is likely to be one of the most abundant cetaceans encountered throughout the Chukchi Sea.

2. MYSTICETES (BALEEN WHALES)

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 3,000 animals (Woodby and Botkin 1993). Up to the early 1990s, the population size was believed to be increasing at a rate of about 3.2% per year (Zeh et al. 1996) despite annual subsistence harvests of 14–74 bowheads from 1973 to 1997 (Suydam et al. 1995). A census in 2001, yielded an estimated annual population growth rate of 3.4% (95% CI 1.7–5%) from 1978 to 2001 and a population size (in 2001) of ~10,470 animals (George et al. 2004, revised to 10,545 by Zeh and Punt [2005]). A population estimate from photo identification data collected in 2004 was 11,800 (Koski et al. 2009), which further supports the estimated 3.4% population growth rate. Assuming a continuing annual population growth of 3.4%, the 2010 bowhead population may number around 14,200 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 some bowhead whales continue migrating west past Barrow and through the Chukchi Sea to Russian waters before turning south toward the Bering Sea (Quakenbush 2007; Quakenbush et al. 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 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. 1999a; Blackwell et al. 2004, 2008; Greene et al. 2007). Satellite tracking of bowheads has also shown that some whales move to the Chukchi Sea prior to September (ADFG 2009). Consistent with this, Nuiqsut whalers have stated that the earliest arriving bowheads have apparently reached the Cross Island area earlier in recent years than formerly (T. Napageak, pers. comm.). In 2007 the MMS and the National Marine Mammal Laboratory (NMML) initiated the Bowhead Whale Feeding Ecology Study (BOWFEST) focusing on late summer oceanography and prey densities relative to bowhead distribution (Rugh [ed.] 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). 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 49 to 656 ft (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, and that is 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. 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 (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.

Most spring-migrating bowhead whales will likely pass through the Chukchi and Beaufort seas prior to the start of the proposed survey. However, a few whales that may remain in the Chukchi Sea or in the Barrow area during the summer could be encountered during the survey activities or by transiting vessels. More encounters with bowhead whales are expected during the westward fall migration in September and October. Most bowheads migrating in September and October appear to transit across the northern portion of the Chukchi Sea to the Chukotka coast before heading south toward the Bering Sea (Quakenbush et al. 2009). Some of these whales have traveled well north of the planned operations, but others have passed near to or through the proposed project area. Statoil will operate in consultation with stakeholders to eliminate disturbance to subsistence bowhead whaling activities in the Beaufort Sea (near Barrow) and by villagers along the Chukchi Sea coast.

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 ±3,122 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 ±1,780 in winter 2001–2002. The population estimate increased during winter 2006–2007 to 20,110 ±1,766 (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 4,971 mi (8,000 km), generally along the west coast of North America, to the main summer feeding grounds in the northern Bering and Chukchi seas (Tomilin 1957; Rice and Wolman 1971; Braham 1984; Nerini 1984; Moore et al. 2003; Bluhm et al. 2007). Most gray whales begin the 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 routinely feed in the Chukchi Sea during the summer. Moore et al. (2000b) reported that during the summer, gray whales in the Chukchi Sea were clustered along the shore primarily between Cape Lisburne and Point Barrow and were associated with shallow, coastal shoal habitat. In autumn, gray whales were clustered near shore at Point Hope and between Icy Cape and Point Barrow, as well as in offshore waters northwest of Point Barrow at Hanna Shoal and southwest of Point Hope. Thomas et al. (2009) reported that gray whale sighting rates and abundance were greater in the 0–3 mi (0–5 km) offshore band in 2006, and in the 16–19 mi (25–30 km) band in 2007 and 2008 during aerial surveys of the nearshore area of the eastern Chukchi Sea. They suggested that the difference in gray whale distribution in 2006 vs. 2007 and 2007 may have been due to differences in food availability and perhaps ice conditions.

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 (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 [eds.] 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. 2008) 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., unpublished 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, unpublished data). However, no gray whales were sighted during cruises north of Barrow in 2002 or 2005 (Harwood et al. 2005; Haley and Ireland 2006).

Small numbers of gray whales could be encountered during the proposed seismic survey in Chukchi Sea in 2010. Although they are most common in portions of the Chukchi Sea close to shore, gray whales may also occur in offshore areas of the Chukchi Sea, particularly over offshore shoals.

Minke Whale (Balaenoptera acutorostrata)

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

Minke whales range into the Chukchi Sea but are not likely to occur in the Beaufort Sea. 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. (2009) reported eight and five Minke whale sightings in 2006 and 2007, respectively, during vessel-based surveys in the Chukchi Sea, and Haley et al. (2009a) reported 26 Minke whale sightings during similar vessel-based surveys in the Chukchi Sea in 2008. Small numbers of Minke whales could be encountered during the proposed exploratory activities in the Chukchi Sea in 2010.

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 to California (Gambell 1985). Three fin whale sightings were made in 2008 (from industry vessels and NMFS/NMML survey aircraft) in the northern Chukchi Sea off of Ledyard Bay. Population estimates for the entire North Pacific population range from 14,620 to 18,630. 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. 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. 2009a). NMML observers also observed and photographed a fin whale off Pt. Lay in 2008. Fin whale is listed as "Endangered" under the ESA and by IUCN, is classified as a strategic stock by NMFS, and it is a CITES Appendix I species (Table 1).

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 the 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 46 and 49 ft (14 and 15 m) 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. Haley et al. (2009b) 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. Whether these humpback whale sightings in the Chukchi and Beaufort seas are related to climate changes in the Arctic in recent years is unknown. Small numbers of humpback whales could occur within or near the project area in the Chukchi Sea but would be less likely to occur near the Beaufort Sea project area.

3. PINNIPEDS

Bearded Seal (Erignathus barbatus)

Bearded seals are associated with sea ice and have a circumpolar distribution (Burns 1981b). The Alaska stock of bearded seals, which occupy the Bering, Chukchi, and Beaufort seas, may consist of about 250,000–300,000 individuals (Angliss and Allen 2009), however, 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. There is though an increasing concern about the future of the bearded seal due to receding ice conditions and potential habitat loss. NMFS conducted a status review for the bearded seal in 2008, but failed to make a determination within a year and was sued for delaying protection of Arctic seals under the ESA (CBD 2008). On 25 September 2009 a federal judge agreed to a settlement that requires NMFS to decide by 1 November 2010 whether bearded seals merit listing as a threatened or endangered species due to threats from global warming.

Bearded seal is the largest of the northern phocids. 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. From mid-April to June as the ice recedes, bearded seals migrate northward from the Bering Sea through the Bering Strait to habitats along the margin of the pack ice in the central or northern Chukchi Sea. 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. During the open water period, bearded seals occur mainly in relatively shallow areas, because they are predominantly benthic feeders (Burns 1981b) that prefer areas of water no deeper than 656 ft (200 m; e.g., Harwood et al. 2005). 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 <656 ft (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 656 ft (200 m) deep.

In Alaskan waters, bearded seals occur over the continental shelves of the Bering, Chukchi, and Beaufort seas (Burns 1981b). 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. Reiser et al. (2009) reported bearded seal densities ranging from 0.01 to 0.03 seals/km^2 in the summer and fall, respectively, during vessel-based surveys in the Chukchi Sea. 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 survey counts of seals on ice in late May and early June. Bearded seal densities in the pack ice of the northern Chukchi Sea appear to be low; only three bearded seals were observed during a survey that passed through the proposed seismic survey area in early August of 2005 (Haley and Ireland 2006).

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). Spotted seals overwinter in the Bering Sea and inhabit the southern margin of the ice during spring (Shaughnessy and Fay 1977). During the summer spotted seals are found in Alaska from Bristol Bay through western Alaska to the Chukchi and Beaufort seas. They migrate south from the Chukchi Sea and through the Bering Sea in October (Lowry et al. 1998).

An early estimate of the size of the world population of spotted seals was 335,000–450,000, and the size of the Bering Sea population, including animals in Russian waters, was estimated to be 200,000–250,000 animals (Burns et al. 1973, cited in Angliss and Allen 2009). 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 4,145 seals hauled out on the Bering Sea pack ice (Rugh et al. 1993), Angliss and Allen (2009) estimated the Alaskan population at 59,214 animals. Because of the concern about the future of ice seals due to receding ice conditions and associated potential habitat loss, NMFS conducted a status review of the spotted seal. Preliminary analyses from 2007 and 2008 survey data in the central and eastern Bering Sea provided a provisional abundance estimate of 101,568 (SE = 17,869) spotted seals in that area (Boveng et al. 2009). Based on this status review NMFS determined not to list the two spotted seal populations inhabiting US waters under the ESA, because they are currently not in danger of extinction or likely to become endangered in the foreseeable future.

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. From July until September, 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). 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. In summer, they are rarely seen on the pack ice, except when the ice is close to the 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).

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 2,200 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.

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. Ringed seals are year-round residents in the northern Chukchi and Beaufort Seas and it is the most frequently encountered seal species in those areas (e.g., Haley et al. 2009b).

No estimate for the size of the Alaska ringed seal stock is currently available (Angliss and Allen 2009). In the 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). Aerial surveys flown perpendicular to the eastern Chukchi Sea coast from Shishmaref to Barrow in 1999 and 2000 yielded an average abundance estimate of 230,673 (Bengtson et al. 2005). The Alaska stock of ringed seals is not endangered, and is not classified as a strategic stock by NMFS. There is though an increasing concern about the future of the ringed seal due to receding ice conditions and potential habitat loss. NMFS conducted a status review for the ringed seal in 2008, but failed to make a determination within a year and was sued for delaying protection of Arctic seals under the ESA (CBD 2008). On 25 September 2009 a federal judge agreed to a settlement that requires NMFS to decide by 1 November 2010 whether ringed seals merit listing as a threatened or endangered species due to threats from global warming.

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).

Based on aerial surveys flown in 1999 and 2000 in the eastern Chukchi Sea average density of ringed seals was estimated to be 1.9 seals/km^2 in 1999 (range 0.37–16.32) and 1.6 seals/km^2 in 2000 (range 0.42–19.4), with generally higher densities in nearshore than offshore locations. The highest densities of ringed seals were found in coastal waters south of Kivalina and near Kotzebue Sound (Bengtson et al. 2005). Vessel-based observations from industry activities in the Chukchi Sea reported seal densities (the majority assumed to be ringed seals) ranging from 0.054 to 0.171 seals/km^2 in the summer and fall, respectively (Haley et al. 2009b). Marine mammal observers aboard the Healy sighted as many as 50 ringed seals along 1,492 mi (2,401 km) of trackline between 70°N and 81°N during two weeks of travel in and north of the Chukchi Sea during August 2005 (Haley and Ireland 2006). Ringed seal will likely be the most abundant marine mammal species encountered in the Chukchi Sea project area.

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 1981a). Little is known about their summer and fall distribution, but Kelly (1988) suggests that they move into the southern Chukchi Sea based on a review of sightings during the summer. However, ribbon seals appeared to be relatively rare in the northern Chukchi Sea during recent vessel-based surveys in summer and fall of 2006 and 2007 with only three sightings among 1,778 sightings of seals identified to species (Haley et al. 2009b). Thus ribbon seals are expected to be rare in the proposed survey area in the Chukchi Sea. In response to a petition to list the ribbon seal under the Endangered Species Act (CBD 2007), NMFS announced that listing of ribbon seal was not warranted at this time (NMFS 2008).

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.

Statoil requests an IHA pursuant to Section 101(a)(5)(D) of the MMPA for incidental take by harassment during its planned 3D marine seismic survey in the Chukchi Sea during mid July–November 2010.

Sounds generated by the operations outlined in Section I and II have the potential to take marine mammals by harassment. Sound sources with the potential to “harass” marine mammals include airguns and the pinger system used during the surveys. Harassment of animals can potentially occur when marine mammals near the activities are exposed to the pulsed sounds generated by the airguns and the pinger system. 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 Section 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 injury or death is anticipated, given the nature of the seismic survey operations and the proposed mitigation measures (see Section XI, "Mitigation Measures").

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 proposed open water seismic survey activities outlined in Sections I and II have the potential to disturb or displace small numbers of marine mammals. These potential effects, as summarized in Section VII below, will not exceed what is defined in the 1994 amendments to the MMPA as "Level B" harassment (behavioral disturbance). The mitigation measures to be implemented during this survey are based on level B harassment criteria using 160 dB re 1µPa rms, and will as such minimize any potential risk of injury, such as damage to the hearing apparatus. No take by injury or death is likely, given the nature of the activities and proposed monitoring and mitigation measures. Section VII provides a summary of potential impacts from sounds on marine mammals, with more detailed background information in Appendix C.

This section describes the methods used to estimate the numbers of marine mammals that might be "taken by harassment" during Statoil's proposed marine seismic survey in the Chukchi Sea. Density estimates are based on the best available peer reviewed scientific data, when available. In cases where the best available data were collected in regions, habitats, or seasons that differ from the proposed survey activities, adjustments to reported population or density estimates were made to account for these differences insofar as possible. Species abundance information obtained from recent marine mammal surveys conducted near to or in the proposed survey area has been provided for completeness and to describe the current knowledge of the species. Most of these data are preliminary or as yet unpublished.

The estimated number of animals potentially harassed was calculated by multiplying the expected densities (in nr/km^2) by the anticipated area ensonified by levels of ≥160 dB re 1µPa. Estimates of the number of animals potentially impacted were conducted separately for the 3D survey area and the 2D survey lines. For the 3D survey area, the anticipated area ensonified by sound levels of ≥160 dB was calculated as an area encompassing a 8.1 mi (13 km) radius extending from each point of the survey area perimeter (hereafter called the 160 dB exposed survey area). This approach was taken because closely spaced survey lines and large cross-track distances of the ≥160 dB radii result in repeated exposure of the same area of water. Excessive amounts of repeated exposure leads to an overestimation of the number of animals potentially exposed. For the 2D survey lines the area ensonified by sound levels of ≥160 dB was calculated as the total line kilometers multiplied by 2 times the 8.1 mi (13 km) ≥160 dB safety radius. The following subsections describe in more detail the data and methods used in deriving at the estimated number of animals potentially "taken by harassment" during the proposed survey. It provides information on the expected marine mammal densities, estimated distances to received levels of 190, 180, 160, and 120 dB re 1µPa and the calculation of anticipated areas ensonified by levels of ≥160 dB.

1. MARINE MAMMAL DENSITY ESTIMATES

There is some uncertainty about the representativeness of the data and assumptions used in the "take" calculations. To provide some allowance for the uncertainties, "maximum estimates" as well as "average estimates" of the numbers of marine mammals potentially affected have been derived. For a few marine mammal species, information on density estimates was available, and in those cases, the average and maximum estimates were calculated from the survey data. In other cases only one or no applicable estimate was available so correction factors were used to arrive at "average" and "maximum" estimates. These are described in detail in the following sections. Except where noted, the "maximum" estimates have been calculated as 4× the "average" estimates. The densities presented are believed to be similar to, or in most cases higher than, the densities that will actually be encountered during the survey.

Not all published results from visual observations have applied correction factors that account for detectability and availability bias. Detectability bias is associated with diminishing sightability with increasing lateral distance from the survey trackline. Availability bias refers to the fact that not all animals are at the surface and that there is therefore <100% probability of sighting an animal that is present along the survey trackline. Some sources below included correction factors in the reported densities (e.g., ringed seals in Bengtson et al. 2005) and the best available correction factors were applied to reported results when they had not already been included (e.g., Moore et al. 2000b).

Estimated densities of marine mammals in the Chukchi Sea during the summer (July and August) and fall period (September-November) are presented in Table 2 and 3, respectively. Again, "average" and "maximum" densities are shown and unless otherwise noted, maximum densities are 4× average densities.

Cetacean Densities

Nine species of cetaceans are known to occur in the Chukchi Sea area of the proposed Statoil project. Only four of these (bowhead, beluga, and gray whales, and harbor porpoise) are likely to be encountered during the proposed survey activities. Three of the nine species (bowhead, fin, and humpback whales) are listed as endangered under the ESA. Of these, only the bowhead is likely to be found within the survey area.

Beluga Whale

Summer densities of beluga in offshore waters are expected to be low. Aerial surveys have recorded few belugas in the offshore Chukchi Sea during the summer months (Moore et al. 2000b). Aerial surveys of the Chukchi Sea in 2008-2009 flown by the NMML as part of the Chukchi Offshore Monitoring in Drilling Area project (COMIDA) have only reported 5 beluga sightings during >8,700 mi (>14,000 km) of on-transect effort, only 2 of which were offshore (COMIDA 2009). Additionally, only one beluga sighting was recorded during >37,904 mi (>61,000 km) of visual effort during good visibility conditions from industry vessels operating in the Chukchi Sea in July–August of 2006–2008 (Haley et al. 2009b). If belugas are present during the summer, they are more likely to occur in or near the ice edge or close to shore during their northward migration. Expected densities were calculated from data in Moore et al. (2000b). Data from Moore et al.

(2000b: Figure 6 and Table 6) used as the average open-water density estimate included two on-transect beluga sightings during 6,639 mi (10,684 km) of on-transect effort in the Chukchi Sea during summer. A mean group size of 7.1 (CV=1.7) was calculated from 10 Chukchi Sea summer sightings present in the BWASP database. A f(0) value of 2.841 and g(0) value of 0.58 from Harwood et al. (1996) were also used in the calculation. The CV associated with group size was used to select an inflation factor of 2 to estimate the maximum density that may occur in both open-water and ice-margin habitats. Specific data on the relative abundance of beluga in open-water versus ice-margin habitat during the summer in the Chukchi Sea is not available. However, Moore et al. (2000b) reported higher than expected beluga sighting rates in open-water during fall surveys in the Beaufort and Chukchi seas. This would suggest that densities near ice may actually be lower than open water, but belugas are commonly associated with ice, so an inflation factor of only 2 (instead of 4) was used to estimate the average ice-margin density from the open-water density. Based on the very low densities observed from vessels operating in the Chukchi Sea during non-seismic periods and locations in July–August of 2006–2008 ($0.0001/km^2$; Haley et al. 2009b), the densities shown in Table 2 are likely biased high.

In the fall, beluga whale densities in the Chukchi Sea are expected to be somewhat higher than in the summer because individuals of the eastern Chukchi Sea stock and the Beaufort Sea stock will be migrating south to their wintering grounds in the Bering Sea (Angliss and Allen 2009). Consistent with this, the number of on-effort beluga sightings reported during COMIDA flights in September–October of 2008–2009 was over 3 times more (17) than during July–August with a very similar amount of on-transect effort (COMIDA 2009). However, there were no beluga sightings reported during >11,185 mi (>18,000 km) of vessel based effort in good visibility conditions during 2006–2008 industry operations in the Chukchi Sea. Densities derived from survey results in the northern Chukchi Sea in Moore et al. (2000b) were used as the average density for open-water and ice-margin fall season estimates (see Table 3). Data from Moore et al. (2000b: Table 8) used in the average open-water density estimate included 123 beluga sightings and 27,559 mi (44,352 km) of on-transect effort in water depths 118–164 ft (36–50 m). A mean group size of 2.39 (CV=0.92) came from the average group size of 82 Chukchi Sea fall sightings in waters 115–164 ft (35–50 m) deep present in the BWASP database. A f(0) value of 2.841 and g(0) value of 0.58 from Harwood et al. (1996) were used in the calculation. The CV associated with group size was used to select an inflation factor of 2 to estimate the maximum density that may occur in both open-water and ice-margin habitats. Moore et al. (2000b) reported higher than expected beluga sighting rates in open-water during fall surveys in the Beaufort and Chukchi seas, so an inflation value of only 2 was used to estimate the average ice-margin density from the open-water density. There were no beluga sightings from vessels operating in the Chukchi Sea during non-seismic periods in September–October of 2006–2008 (Haley et al. 2009b).

Bowhead Whale

By July, most bowhead whales are northeast of the Chukchi Sea, within or migrating toward their summer feeding grounds in the eastern Beaufort Sea. No bowheads were reported during 6,639 mi (10,684 km) of on-transect effort in the Chukchi Sea by Moore et al. (2000b). Aerial surveys in 2008–2009 by the NMML as part of the COMIDA project reported four sightings during >8,699 mi (>14,000 km) of on-transect effort. Two of the four sightings were offshore, both of which occurred near the end of August. Bowhead whales were also rarely reported in July–August of 2006–2008 during aerial surveys of the Chukchi Sea coast (Thomas et al. 2009). This is consistent with movements of tagged whales (see ADFG 2009; Quakenbush 2009), all of which moved through the Chukchi Sea by early May 2009, and tended to travel relatively close to shore, especially in the northern Chukchi Sea.

The estimate of bowhead whale density in the Chukchi Sea was calculated by assuming that there was one bowhead sighting during the 6,639 mi (10,684 km) survey effort in the Chukchi Sea during the summer, although no bowheads were actually observed (Moore et al. 2000b). The more recent COMIDA data were not used because the NMML has not released a final report summarizing the data. Only two sightings are present in the BWASP database during July and August in the Chukchi Sea, both of which were of individual whales. The mean group size from combined July–August sightings in the BWASP, COMIDA, and 2006–2008 industry database is 1.33 (CV=0.58). This value, along with a f(0) value of 2 and a g(0) value of 0.07, both from Thomas et al. (2002) were used to estimate a summer density of bowhead whales. 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 deriving at a maximum density from the average density. Bowheads are not expected to be encountered in higher densities near ice in the summer (Moore et al. 2000b), so the same density estimates are used for open-water and ice-margin habitats. Densities from vessel based surveys in the Chukchi Sea during non-seismic periods and locations in July–August of 2006–2008 (Haley et al. 2009b) ranged from 0.0001/km^2 to 0.0005/km^2 with a maximum 95 percent confidence interval (CI) of 0.0019 km^2. This suggests that the densities used in the calculations and shown in Table 2 might be somewhat higher than expected to be observed from vessels near the area of planned operations.

During the fall, bowhead whales migrate west and south from their summer feeding grounds in the Beaufort Sea and Amundsen Gulf to their wintering grounds in the Bering Sea. During this fall migration bowheads are more likely to be encountered in the Chukchi Sea. Moore et al. (2000b: Table 8) reported 34 bowhead sightings during 27,560 mi (44,354 km) of on-transect survey effort in the Chukchi Sea during September–October. Thomas et al. (2009) also reported increased sightings on coastal surveys of the Chukchi Sea during September and October of 2006–2008. Aerial surveys in 2008–2009 (COMIDA 2009) reported 20 bowhead sightings during 8,803 mi (14,167 km) of on-transect effort, eight of which were offshore. GPS tagging of bowheads show that migration routes through the Chukchi Sea are more variable than through the Beaufort Sea (ADFG 2009; Quakenbush 2009). Some of the routes taken by bowheads remain well north or south of the planned survey activities while others have passed near to or through the area. Kernel densities estimated from GPS locations of whales suggest that bowheads do not spend much time (e.g., feeding or resting) in the north-central Chukchi Sea near the area of planned activities (ADFG 2009). The mean group size from September–October Chukchi Sea bowhead sightings in the BWASP database is 1.59 (CV=1.08). This is slightly below the mean group size of 1.85 from all the preliminary COMIDA sightings during the same months, but above the value of 1.13 from only on-effort COMIDA sightings (COMIDA 2009). The same f(0) and g(0) values that were used for the summer estimates above were used for the fall estimates. As with the summer estimates, an inflation factor of 2 was used to estimate the maximum density from the average density in both habitat types. Moore et al. (2000b) found that bowheads were detected more often than expected in association with ice in the Chukchi Sea in September–October, so a density of twice the average open-water density was used as the average ice-margin density. Densities from vessel based surveys in the Chukchi Sea during non-seismic periods and locations in September–October of 2006–2008 (Haley et al. 2009b) ranged from 0.0001/km^2 to 0.0050/km^2 with a maximum 95 percent CI of 0.0480 km^2. This suggests the densities used in the calculations and shown in Table 3 are somewhat higher than are likely to be observed from vessels near the area of planned operations.

Gray Whale

The average open-water summer density was calculated from effort and sightings in Moore et al. (2000b: Table 6) for water depths 118–164 ft (36–50 m) including 4 sightings during 3,901 mi (6,278 km) of on-transect effort. An average group size of 3.11 (CV=0.97) was calculated from all July–August Chukchi Sea gray whale sightings in the BWASP database and used in the summer density estimate. This value was higher than the average group size in the preliminary COMIDA data (1.71; COMIDA 2009) and from coastal aerial surveys in 2006–2008 (1.27; Thomas et al. 2009). Correction factors f(0) = 2.49 (Forney and Barlow 1998) and g(0) = 0.30 (Forney and Barlow 1998; Mallonee 1991) were also used in the density calculation. Since the group size used in the average density estimate was relatively high compared to other data sources and the CV was near to one, an inflation factor of 2 was used to estimate the maximum densities from average densities in both habitat types. Gray whales are not commonly associated with sea ice, but may occur close to sea ice, so the densities for open-water habitat were also used for ice-margin habitat. Densities from vessel based surveys in the Chukchi Sea during non-seismic periods and locations in July–August of 2006–2008 (Haley et al. 2009b) ranged from 0.0009/km^2 to 0.0034/km^2 with a maximum 95 percent CI of 0.0146 km^2. This suggests that the densities used in the calculations and shown in Table 2 are somewhat higher than are expected to be observed from vessels near the area of planned operations.

Gray whale densities are expected to be much higher in the summer months than during the fall when most whales start their southbound migration. Moore et al. (2000b) found that the distribution of gray whales was more widely dispersed through the northern Chukchi Sea and limited to nearshore areas where most whales were observed in water less than 115 ft (35 m) deep. With similar amounts of on-transect effort between summer and fall aerial surveys in 2008–2009, gray whale sightings were three times higher in July–August than in September–October, and five times taking into account all effort and sightings (COMIDA 2009). Thomas et al. (2009) also reported decreased sighting rates of gray whales in the fall.

The on-transect effort and associated gray whale sightings (27 sightings during 44,352 km of on-transect effort) in water depth of 118–164 ft (36–50 m) during autumn (Moore et al. 2000b; 12) was used as the average density estimate for the Chukchi Sea during the fall period. A group size value of 2.49 (CV=1.37) calculated from the BWASP database was used in the density calculation, along with the same f(0) and g(0) values described above. The group size value of 2.49 was again higher than the average group size calculated from preliminary COMIDA data (1.24; COMIDA 2009) and as reported from coastal aerial surveys in 2006–2008 (1.12; Thomas et al. 2009). Densities from vessel based surveys in the Chukchi Sea during non-seismic periods and locations in September–October of 2006–2008 (Haley et al. 2009b) ranged from 0.0011/km^2 to 0.0024/km^2 with a maximum 95 percent CI of 0.0183 km^2. This suggests the densities used in the calculations and shown in Table 3 are somewhat higher than are likely to be observed from vessels near the area of planned operations.

Harbor Porpoise

Harbor Porpoise densities were estimated from industry data collected during 2006–2008 activities in the Chukchi Sea. Prior to 2006, no reliable estimates were available for the Chukchi Sea and harbor porpoise presence was expected to be very low and limited to nearshore regions. For this reason, the data collected from industry vessels was considered to be the best available data. Observers on industry vessels in 2006–2008, however, recorded sightings throughout the Chukchi Sea during the summer and early fall months. Density estimates from 2006–2008 observations during non-seismic periods and locations in July–August ranged from 0.0009/km^2 to 0.0016/km^2 with a maximum 95 percent CI of 0.0016/km^2 (Haley et al. 2009b). The median value from the summer season of those three years (0.0011/km^2) was used as the average open-water density estimate while the high value (0.0016/km^2) was used as the maximum estimate (Table 2). Harbor porpoise are not expected to be present in higher numbers near ice, so the open-water densities were used for ice-margin habitat in both seasons. Harbor porpoise densities recorded during industry operations in the fall months of 2006–2008 were slightly lower and ranged from 0.0002/km^2 to 0.0013/km^2 with a maximum 95 percent CI of 0.0044/km^2. The median value (0.0010/km^2) was again used as the average density estimate and the high value (0.0013/km^2) was used as the maximum estimate (Table 3).

Other Cetaceans

The remaining five cetacean species that could be encountered in the Chukchi Sea during Statoil's planned seismic survey include the humpback whale, killer whale, minke whale, fin whale, and narwhal. Although there is evidence of the occasional occurrence of these animals in the Chukchi Sea, it is unlikely that more than a few individuals will be encountered during the proposed activities. George and Suydam (1998) reported killer whales, Brueggeman et al. (1990) and Haley et al. (2009b) reported minke whale, and COMIDA (2009) and Haley et al. (2009b) reported fin whales off of Ledyard Bay in the Chukchi Sea. Narwhal sightings in the Chukchi Sea have not been reported in recent literature, but subsistence hunters occasionally report observations near Barrow and Reeves et al. (2002) indicate a small number of extralimital sightings in the Chukchi Sea. Minimum density estimates are used for these species.

Pinniped Densities

Four species of pinnipeds may be encountered in the Chukchi Sea: ringed seal, bearded seal, spotted seal, and ribbon seal. Each of these species, except the spotted seal, is associated with both the ice margin and the nearshore area. The ice margin is considered preferred habitat (as compared to the nearshore areas) during most seasons.

Ringed seal and ***bearded seal*** "average" and "maximum" summer ice-margin densities (Table 2) were available in Bengtson et al. (2005) from spring surveys in the offshore pack ice zone (zone 12P) of the northern Chukchi Sea. However, corrections for bearded seal availability, g(0), based on haulout and diving patterns were not available. Densities of ringed and bearded seals in open water are expected to be somewhat lower in the summer when preferred pack ice habitat may still be present in the Chukchi Sea. Average and maximum open-water densities have been estimated as 3/4 of the ice margin densities during the summer for both species. The fall density of ringed seals in the

TABLE 2. Expected densities of cetaceans and seals in areas of the Chukchi Sea, Alaska, during the planned summer (July–August) period of the seismic survey program. Species listed under the U.S. ESA 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				
Monodontidae				
Beluga	0.0033	0.0066	0.0162	0.0324
Narwhal	0.0000	0.0000	0.0000	0.0001
Delphinidae				
Killer whale	0.0001	0.0004	0.0001	0.0004
Phocoenidae				
Harbor porpoise	0.0011	0.0016	0.0011	0.0016
Mysticetes				
Bowhead whale	*0.0018*	*0.0036*	*0.0018*	*0.0036*
Fin whale	*0.0001*	*0.0004*	*0.0001*	*0.0004*
Gray whale	0.0081	0.0162	0.0081	0.0162
Humpback whale	*0.0001*	*0.0004*	*0.0001*	*0.0004*
Minke whale	0.0001	0.0004	0.0001	0.0004
Pinnipeds				
Bearded seal	0.0107	0.0203	0.0142	0.0270
Ribbon seal	0.0003	0.0012	0.0003	0.0012
Ringed seal	0.3668	0.6075	0.4891	0.8100
Spotted seal	0.0073	0.0122	0.0098	0.0162

offshore Chukchi Sea has been estimated as 2/3 the summer densities because ringed seals begin to reoccupy nearshore fast ice areas as it forms in the fall. Bearded seals may begin to leave the Chukchi Sea in the fall, but less is known about their movement patterns so fall densities were left unchanged from summer densities. For comparison, the ringed seal density estimates calculated from data collected during summer 2006–2008 industry operations ranged from 0.0082/km^2 to 0.0221/km^2 with a maximum 95 percent CI of 0.0577/km^2 (Haley et al. 2009b). These estimates are lower than those made by Bengtson et al. (2005) which is not surprising given the different survey methods and timing.

Little information on ***spotted seal*** densities in offshore areas of the Chukchi Sea is available. Spotted seals are often considered to be predominantly a coastal species except in the spring when they may be found in the southern margin of the retreating sea ice, before they move to shore. However, satellite tagging has shown that they sometimes undertake long excursions into offshore waters during summer (Lowry et al. 1994, 1998). Spotted seal densities in the summer were estimated by multiplying the ringed seal densities by 0.02. This was based on the ratio of the estimated Chukchi populations of the two species (Table 1). Chukchi Sea spotted seal abundance was estimated by assuming that 8% of the Alaskan population of spotted seals is present in the Chukchi Sea during the summer and fall (Rugh et al. 1997), the Alaskan population of spotted seals is 59,214 (Angliss and Allen 2009), and that the population of ringed seals in the Alaskan Chukchi Sea is >208,000 animals (Bengtson et al. 2005). In the fall, spotted seals show increased use of coastal haulouts so densities were estimated to be 2/3 of the summer densities.

Ribbon seals have been reported in very small numbers within the Chukchi Sea by observers on industry vessels (two sightings; Haley et al. 2009b). The resulting density estimate of 0.0003/km^2 was used as the average density and a multiplier of 4 was used as the estimated maximum density for both seasons and habitat zones.

TABLE 3. Expected densities of cetaceans and seals in areas of the Chukchi Sea, Alaska, during the fall (September–October) period of the seismic survey program. Species listed under the U.S. ESA 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				
Monodontidae				
Beluga	0.0162	0.0324	0.0324	0.0648
Narwhal	0.0000	0.0000	0.0000	0.0001
Delphinidae				
Killer whale	0.0001	0.0004	0.0001	0.0004
Phocoenidae				
Harbor porpoise	0.0010	0.0013	0.0010	0.0013
Mysticetes				
Bowhead whale	*0.0174*	*0.0348*	*0.0348*	*0.0696*
Fin whale	*0.0001*	*0.0004*	*0.0001*	*0.0004*
Gray whale	0.0062	0.0124	0.0062	0.0124
Humpback whale	*0.0001*	*0.0004*	*0.0001*	*0.0004*
Minke whale	0.0001	0.0004	0.0001	0.0004
Pinnipeds				
Bearded seal	0.0107	0.0203	0.0142	0.0270
Ribbon seal	0.0003	0.0012	0.0003	0.0012
Ringed seal	0.2458	0.4070	0.3277	0.5427
Spotted seal	0.0049	0.0081	0.0065	0.0108

2. SAFETY RADII

As outlined in Section 5, impacts on marine mammals from the planned seismic survey focus on the sound sources of the seismic airguns. 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, 2000). A fourth measure that is increasingly used is the energy, or Sound Exposure Level (SEL), in dB re 1 µPa2 • s. Because the pulses, even when stretched by propagation effects are usually <1 s in duration, the numerical value of the energy is usually lower than the rms pressure level. 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. Additional discussion of the characteristics of airgun pulses is included in Appendix C.

The NMFS commonly refers to rms levels when discussing levels of pulsed sounds that might "harass" marine mammals. This section describes the methodology and underlying assumptions used to estimate the safety radii for received levels of 190, 180, 160 and 120 dB re 1µPa (rms) for pulsed sounds emitted by the airgun array with a total discharge volume of 3000 in^3. More specifications of the airgun array are included in Appendix B. Distances to received sound levels of 160 dB re 1 µPa (rms) will be used to estimate the potential number of marine mammals subject to Level B Harassment and forms the basis for the requested take authorization. Distances to received levels of 160, 180 and 190 dB re 1 µPa (rms) are of importance as safety radii for mitigation purposes.

The basis for the estimation of distances to the four received sound levels from the proposed 3000 in^3 airgun array operating at a depth of 20 ft (6 m) are the 2006, 2007 and 2008 sound source verification (SSV) measurements in the Chukchi Sea of a similar array, towed at a similar depth. The measured airgun array had a total discharge volume of 3,147 in^3 and was composed of three identically-tuned Bolt airgun sub-arrays, totaling 24 airguns (6 clusters of 2 airguns and 12 single airguns). The proposed 3000 in^3 array is also composed of three strings with a total of 26 active airguns in 13 clusters (five clusters of 10 airguns are inactive and will be used as spares). The difference in discharge volume would lead to an expected loss of less than 0.2 dB and is neglected in this assessment. The estimated source level for the full 3000 in^3 array is 245 dB re 1 µPA rms. Without measurement data for the specific site to be surveyed, it is reasonable to adopt the maximum distances obtained from a similar array during previous measurements in the Chukchi Sea. Table 4 summarizes the distances to received levels of 190, 180 160, and 120 dB re 1 µPa (rms) from SSV measurements of the 3,147 in^3 airgun array used in the Chukchi Sea during 2006–2008. Table 5 lists the pre-season distances that are adopted for the proposed survey. Distances for received levels of 120 dB are highly variable, in part because the bottom geoacoustic properties will have a major effect on received levels at such distances. It is estimated that the distances to received levels of 120 dB of the proposed array will fall within the ranges listed in Table 4. To estimate the distances to various received levels from the 60 in^3 mitigation gun the data from previous measurements of the 30 in^3 gun were used. In general the pressure increase relative to a 30 in^3 gun can be derived by calculating the square root of (60/30), which is 1.41. This means that the dB levels for the sound pressure levels of a 60 in^3 will increase by ~3 dB (20Log[1.41]) compared to the 30 in^3 gun. The distances as summarized in Table 5 were derived by adding 3 dB to the constant term of the equation RL = 226.6 - 21.2log(R) - 0.00022R (Figure 3.17 in Funk et al. 2008). The estimated source level of this single 60 in^3 airgun is 230 dB re 1 µPa rms.

The 160–190 dB re 1µPa (rms) radii for the airgun source will be measured during acoustic verification measurements at the beginning of seismic data acquisition. Based on these measurements the distance to received levels of 120 dB from the 3000 in^3 airgun array can be calculated. The use of ≥180 and ≥190 dB safety criteria is consistent with guidelines listed for cetaceans and pinnipeds, respectively, by NMFS (2000) and other guidance by NMFS. When marine mammals are detected in the water at locations within or about to enter the appropriate ≥180 dB or ≥190 dB radii, the airguns will be powered down immediately (or shut down if necessary). A single 60 in^3 sleeve airgun will be used as the power down (or mitigation) source. More details on mitigation and monitoring is provided in Section XI and XIII. Statoil is aware that NMFS may release new noise-exposure guidelines (NMFS 2005) and is prepared to revise its procedures for estimating numbers of mammals "taken", safety radii, etc., as may be required by the new guidelines, if issued.

TABLE 4. Distances to received sound levels of ≥190, 180, 170, 160, and 120 dB re 1 μPa (rms) from the 3147 in^3 airgun array and the 30 in^3 mitigation gun used for "take calculations" during 2006, 2007 and 2008 seismic surveys in the Chukchi Sea as reported in the 90-day reports.

Received levels (dB re 1 μPa rms) [a]	Distance (m) 3147 in^3 airgun array			Distance (m) 30 in^3 mitigation airgun	
	2006[b]	2007[c]	2008[c]	2007[c]	2008[c]
190	460	550	610	10	10
180	1,400	2,470	2,000	24	10
160	8,000	8,100	13,000	1,360	1,900
120	82,890	66,000	120,000	41,100	47,000
Water depth (m)	42	--	37-43	--	37-43

[a] Received levels of airgun sounds are expressed in dB re 1 μPa (rms, averaged over pulse duration).
[b.] Blackwell et al. 2007
[c.] Funk et al. 2008
[d.] Hannay and Warner 2009

TABLE 5. Estimated distances to received sound levels ≥190, 180, 170, 160, and 120 dB re 1 μPa (rms) from the 3000 in^3 airgun array and the 60 in^3 mitigation gun of the proposed seismic survey. These distances are based on measurements in the Chukchi Sea from a similar airgun array (see Table 4).

Received levels (dB re 1 μPa rms) [a]	Distance (m)	
	3000 in^3 (full airgun array)	60 in^3 (mitigation gun)
190	700	75
180	2,500	220
160	13,000	1,800
120	70,000-120,000	50,000

[a] Received levels of airgun sounds are expressed in dB re 1 μPa (rms, averaged over pulse duration).

3. POTENTIAL NUMBER OF "TAKES BY HARASSMENT"

This subsection provides estimates of the number of individuals potentially exposed to sound levels ≥160 dB re 1 μPa (rms). The estimates are based on a consideration of the number of marine mammals that might be disturbed appreciably by operations in the Chukchi Sea and the anticipated area exposed to rms sound levels of 160 dB.

As described above, marine mammal density estimates for the Chukchi Sea have been derived for two time periods, the summer period (July–August), and the fall period (September–October). Animal densities encountered in the Chukchi Sea during both of these time periods will further depend on the habitat zone within which the source vessel is operating, i.e., open water or ice margin. The seismic source vessel is not an icebreaker and cannot tow survey equipment through pack ice. Under this assumption, densities of marine mammals expected to be observed near ice margin areas have been applied to 10% of the proposed 3D survey area and 2D tracklines in both seasons. Densities of marine mammals expected to occur in open water areas have been applied to the remaining 90% of the 3D survey and 2D tracklines area in both seasons.

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

- the anticipated area to be ensonified to the specified level in each season and habitat zone to which that density applies, by
- the expected species density.

The numbers of individuals potentially exposed were then summed for each species across the two seasons and habitat zones. Some of the animals estimated to be exposed, particularly migrating bowhead whales, might show avoidance reactions before being exposed to ≥160 dB re 1 μPa (rms). Thus, these calculations actually estimate the number of individuals potentially exposed to ≥160 dB that would occur if there were no avoidance of the area ensonified to that level.

3D Seismic Survey Area

The size of the proposed 3D seismic survey area is 915 mi^2 (2,370 km^2) and located >100 mi (160 km) offshore. Approximately 1/4 of the area (~234 mi [~606 km^2]) is expected to be surveyed in August (weather depending). This area, with a 160 dB radius of 8 mi (13 km) along each point of its perimeter equals a total area of ~1,081 mi^2 (~2,799 km^2). Summer marine mammal densities from Table 2 have been applied to this area. The other 3/4 of the survey area (~687 mi^2 [~1,779 km^2]) is expected to be covered in September–October. This area, also with a 160 dB radius of 8 mi (13 km) along each point of its perimeter results in a total area of ~1,813 mi^2 (~4,695 km^2). Fall marine mammal densities from Table 3 have been applied to this area. Based on these assumptions and those described above, the estimates of marine mammals potentially exposed to sounds ≥160 dB in the Chukchi Sea from seismic data acquisition in the 3D survey area were calculated in (Table 6). For the common species, the requested numbers were calculated as described above and based on the average and maximum densities reported. For less common species, for which minimum density estimates were assumed, the numbers were set to a minimum to allow for chance encounters. The mitigation gun (60 in^3) will be active during turns extending about 1.6 mi (2.5 km) outside the 3D survey area. The estimated 160 dB radius for the 60 in^3 mitigation gun is 5,906 ft (1,800 m) and therefore falls well within the area expected to be exposed to received sound levels of ≥160 dB of the 3D survey area.

2D Seismic Survey Lines

Seismic data along the ~420 mi (675 km) of four 2D survey tracklines might be acquired with the full airgun array if access to the 3D survey area is restricted (e.g., ice conditions), or 3D acquisition progress is better than anticipated. Under the assumption that these restrictive weather conditions will mainly be an issue in the early summer season, 80 % of the 2D tracklines are assumed to be acquired during August and 20% during the fall. The total area potentially exposed to ≥160 dB from these tracklines was calculated with the trackline sections outside the 3D survey area. Excluding these sections results in a total trackline length of ~285 mi (460 km). With a 160 dB radius of ~8 mi (13 km) this results in a total exposed area of ~2,309 mi^2 (5,980 km^2). Such summer densities were used for 80% of the total area (1,847 mi^2 [4,784 km^2]) and fall densities for the remaining 20% (462 mi^2 [1,196 km^2]). Following a similar approach as for the 3D survey area, numbers of more common marine mammal species were calculated based on the average and maximum densities and for less common species the numbers were set to a minimum to allow for chance encounters. The results of estimates of marine mammals potentially exposed to sounds ≥160 dB in the Chukchi Sea from seismic data acquisition along the 2D tracklines are presented in Table 7.

Summary

Based on density estimates, the endangered cetacean species expected to be most exposed to received sound levels of ≥160 dB is the bowhead whale, unless they 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. Two other endangered cetacean species that may be encountered in the area (fin whale and humpback whale) are unlikely to be exposed given their known distribution patterns. Our estimate of the number of bowhead whales potentially exposed to ≥160 dB during data acquisition in the 3D survey area ranges between 95 and 190 (Table 6), and for the 2D tracklines 32 and 63 (Table 7). Our estimate of the number of fin and humpback whales potentially exposed to ≥160 dB is between 1 and 5 for both the 3D survey and 2D lines.

The other cetacean species most likely to be exposed to airgun sounds with received levels ≥160 dB are gray whales, beluga whales, and the harbor porpoise. Average and maximum estimates of the number of exposures for these species during the 3D seismic survey are 52 and 104 (gray whale), 97 and 193 (beluga), and 8 and 11 (harbor porpoise; Table 6). For the 2D survey tracklines these numbers are 46 and 92, 43 and 87, and 6 and 9, for gray whale, beluga and harbor porpoise, respectively (Table 7). The narwhal, killer whale and minke whale are not common in the area and the estimated numbers of exposure for these species is therefore lower (between 0 and 5; Table 6, 7).

Of the pinnipeds, the ringed seal is the most widespread and abundant species in ice-covered arctic waters. This species is therefore most likely to be encountered and potentially exposed to received sound levels of ≥160 dB re 1 μPa (rms) during seismic data acquisition in the proposed 3D survey area and along the 2D tracklines. The average and maximum number of ringed seals that might be encountered and exposed to ≥160 dB is estimated to be 2,253 and 3,732 for the 3D survey area and 2,117 and 3,506 for the 2D lines.

The other two seal species (other than the Pacific walrus) that are expected to be encountered and thus potentially exposed to received sound levels of ≥160 dB are the bearded and spotted seal. Estimated number of exposures during the 3D survey range from 82 to 157 for the bearded seal and from 45 to 74 for the spotted seal (Table 6). For the 2D survey tracklines these numbers are 66 and 125, and 42 and 70, respectively (Table 7). The ribbon seal is unlikely to be encountered, but their presence cannot be ruled out. Number of exposures is estimated to be between 0 and 5.

TABLE 6. Estimates of the total numbers of animals for each marine mammal species that may potentially be exposed to received underwater sound levels of ≥160 dB during Statoil's proposed ***3D seismic survey*** in summer (August) and fall (September–November) in the Chukchi Sea, Alaska.

	Number of Exposures to Sound Levels ≥160 dB re 1uPa													
	Summer						**Fall**							
	Open Water		**Ice Margin**		**Total**		**Open Water**		**Ice Margin**		**Total**		**Grand Total**	
	Avg.	**Max.**	**Avg.**	**Max.**	**Avg.**	**Max.**	**Avg.**	**Max.**	**Avg.**	**Max.**	**Avg.**	**Max.**	**Avg.**	**Max.**
Odontocetes														
Beluga	8	17	5	9	13	26	68	137	15	30	84	167	97	193
Narwhal	0	0	0	0	0	0	0	0	0	0	0	0	0	5
Killer whale	0	1	0	0	0	1	0	2	0	0	0	2	1	5
Harbor porpoise	3	4	0	0	3	4	4	5	0	1	5	6	8	11
Mysticetes														
Bowhead whale	5	9	1	1	5	10	74	147	16	33	90	180	95	190
Fin whale	0	1	0	0	0	1	0	2	0	0	0	2	1	5
Gray whale	20	41	2	5	23	45	26	52	3	6	29	58	52	104
Humpback Whale	0	1	0	0	0	1	0	2	0	0	0	2	1	5
Minke whale	0	1	0	0	0	1	0	2	0	0	0	2	1	5
Pinnipeds														
Bearded seal	27	51	4	8	31	59	45	86	7	13	52	98	82	157
Ribbon seal	1	3	0	0	1	3	1	5	0	1	1	6	2	9
Ringed seal	924	1530	137	227	1061	1757	1039	1720	154	255	1192	1975	2253	3732
Spotted seal	18	31	3	5	21	35	21	34	3	5	24	39	45	74

NOTE: Due to ice cover restrictions of the proposed survey, 90% of the seismic survey area was considered as open water region and 10% as ice margin region.

TABLE 7. Estimates of the total numbers of animals for each marine mammal species that may potentially be exposed to received underwater sound levels of ≥160 dB during Statoil's proposed ***2D tie line survey*** in summer (August) and fall (September–November) in the Chukchi Sea, Alaska.

	Number of Exposures to Sound Levels ≥160 dB re 1uPa													
	Summer						**Fall**							
	Open Water		**Ice Margin**		**Total**		**Open Water**		**Ice Margin**		**Total**		**Grand Total**	
	Avg.	**Max.**	**Avg.**	**Max.**	**Avg.**	**Max.**	**Avg.**	**Max.**	**Avg.**	**Max.**	**Avg.**	**Max.**	**Avg.**	**Max.**
Odontocetes														
Beluga	28	57	16	31	44	88	35	70	8	16	43	85	87	173
Narwhal	0	0	0	0	0	0	0	0	0	0	0	0	0	5
Killer whale	1	3	0	0	1	4	0	1	0	0	0	1	1	5
Harbor porpoise	9	14	1	2	11	15	2	3	0	0	2	3	13	18
Mysticetes														
Bowhead whale	16	31	2	3	17	34	37	75	8	17	46	92	63	126
Fin whale	1	3	0	0	1	4	0	1	0	0	0	1	1	5
Gray whale	70	140	8	16	78	155	13	27	1	3	15	30	92	185
Humpback Whale	1	3	0	0	1	4	0	1	0	0	0	1	1	5
Minke whale	1	3	0	0	1	4	0	1	0	0	0	1	1	5
Pinnipeds														
Bearded seal	92	174	14	26	105	200	23	44	3	6	26	50	132	250
Ribbon seal	3	10	0	1	3	11	1	3	0	0	1	3	4	14
Ringed seal	3159	5231	468	775	3627	6006	529	876	78	130	607	1006	4234	7012
Spotted seal	63	105	9	16	73	120	11	17	2	3	12	20	85	140

NOTE: Due to ice cover restrictions of the proposed survey, 90% of the seismic survey area was considered as open water region and 10% as ice margin region.

4. CONCLUSIONS RELATED TO "TAKE ESTIMATES"

Cetaceans

Most of the bowhead whales encountered during the summer will likely show overt disturbance (avoidance) only if they receive airgun sounds with levels ≥160 dB re 1 µPa (rms). Odontocete reactions to seismic energy pulses are usually assumed to be limited to shorter 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 6–12 mi (10–20 km) of seismic vessels during aerial surveys (Miller et al. 2005). Belugas will likely occur in small numbers in the Chukchi Sea during the survey period and few will likely be affected by the survey activity.

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 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 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 an average of ~158 bowheads may be exposed at this level (for 3D and 2D numbers added together). This is <1% of the Bering–Chukchi–Beaufort population of ~14,420 assuming a 3.4% annual population growth from the 2004 estimate of 11,800 animals (Koski et al. 2009).

Some beluga whales 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 average estimates of the number of belugas that might be exposed to ≥160 dB during both the 3D survey and 2D tracklines (~184) represents <1% of the Beaufort and Eastern Chukchi Sea stocks.

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, and shut downs or power downs when marine mammals are seen within defined ranges will further reduce short-term reactions and minimize any effects on hearing sensitivity. In all cases, the effects are expected to be short-term, with no lasting biological consequence. Potential impacts on subsistence resources are addressed in Section VIII.

Pinnipeds

Three pinniped species are likely to be encountered in and near the seismic survey area, of which the ringed seal is by far the most abundant marine mammal species. The average estimate of the number of ringed seals exposed to airgun sounds at received levels ≥160 dB re 1 µPa (rms) during seismic data acquisition in the 3D survey area is 2,253, and 4,234 for the 2D tracklines. These number represent <1% of the Bering–Chukchi Sea stock and Beaufort Sea stock. The estimated numbers of exposure for the bearded seals and spotted seals also represent <1% of their populations. 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. Potential impacts on subsistence resources are addressed in Section VIII.

VII. ANTICIPATED IMPACT ON SPECIES OR STOCKS

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

In this section we summarize the potential impacts of airgun operations on marine mammals, where relevant specific to the proposed survey. A more comprehensive review of the relevant background information appears in Appendix C. In the text below we have not included all relevant literature references, however, these are provided in the relevant sections of Appendix C and in the Literature Cited section of that Appendix.

1. 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). 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 C, Section 3. Numerous studies have shown that marine mammals at distances more than a few kilometers from operating seismic vessels often show no apparent response—see Appendix C, Section 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 and small odontocetes seem to be more tolerant of exposure to airgun pulses than are baleen whales.

Masking

Introduced underwater sound will, through masking, reduce the effective communication distance of a marine mammal species if the frequency of the source is close to that used as a signal by the marine mammal, and if the anthropogenic sound is present for a significant fraction of the time (Richardson et al. 1995). Masking effects of pulsed sounds (even from large arrays of airguns) on marine mammal calls and other natural sounds are expected to be limited, although there are few specific studies on this. Some whales are known to continue calling in the presence of seismic pulses and their calls can be heard between the pulses (e.g., Richardson et al. 1986; McDonald et al. 1995; Greene et al. 1999a,b; Nieukirk et al. 2004; Smultea et al. 2004; Holst et al. 2005a,b, 2006; Dunn and Hernandez 2009). Bowhead whales in the Beaufort Sea may decrease their call rates in response to seismic operations, although movement out of the area might also have contributed to the lower call detection rate (Blackwell et al. 2009a,b). In contrast, Di Iorio and Clark (2009) found evidence of increased calling by blue whales during operations by a lower-energy seismic source—a sparker. Masking effects of seismic pulses are expected to be negligible in the case of the smaller odontocete cetaceans, given the intermittent nature of seismic pulses. Also, the sounds important to small odontocetes are predominantly at much higher frequencies than are airgun sounds. Masking effects, in general, are discussed further in Appendix C, Section 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 (e.g., Lusseau and Bejder 2007; Weilgart 2007). Given the many uncertainties in predicting the quantity and types of impacts of noise on marine mammals, it is common practice to estimate how many mammals were present within a particular distance of industrial activities and/or exposed to a particular level of industrial sound. In most cases this approach likely overestimates the numbers of marine mammals that are 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 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, but for many species there are no data on responses to marine seismic surveys

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, as reviewed in Appendix C, Section 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 1µPa 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 2 to 9 mi (4 to 15 km) from the source. A substantial proportion of the baleen whales within those distances may show avoidance or other disturbance reactions to the airgun array. Subtle behavioral changes sometimes become evident at somewhat lower received levels, and studies reviewed in Appendix C, Section 5.1 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 1µPa rms.

Bowhead whales migrating west across the Alaskan Beaufort Sea in autumn, in particular, are unusually responsive, with avoidance occurring out to distances of 12–19 mi (20–30 km) from a medium-sized airgun source (Miller et al. 1999; Richardson et al. 1999). However, more recent research on bowhead whales (Miller et al. 2005; Lyons et al. 2008; 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 1µPa rms (Richardson et al. 1986; Ljungblad et al. 1988; Miller et al. 1999).

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 1µPa 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 (Würsig et al. 1999; Johnson et al. 2007; Meier et al. 2007; Yazvenko et al. 2007).

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 C have been reported for toothed whales. However, there are recent systematic data on sperm whales, and 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; and many others as summarized in Appendix C, Section 5.2).

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 6–12 mi (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 6–12 mi (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 1µPa) before exhibiting aversive behaviors. With the presently-planned source, such levels would be limited to distances less than 656 ft (200 m) of the 26-airgun array in shallow water. The reactions of belugas to the Statoil 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).

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 >43 mi [>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).

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 (Appendix 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. For the proposed survey a ≥160 dB disturbance criterion will be used for all marine mammal species.

Pinnipeds

Pinnipeds are not likely to show a strong avoidance reaction to the airgun sources that will be used. Visual monitoring from seismic vessels has shown only slight (if any) avoidance of airguns by pinnipeds, and only slight (if any) changes in behavior—see Appendix C, Section 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). Vessel-based monitoring in the Alaskan Chukchi and Beaufort seas during 2006–2008 show indications of a tendency for phocid seals to exhibit localized avoidance of the seismic source vessel when airguns are firing (Reiser et al. 2009). 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. As for delphinids, a ≥170 dB disturbance criterion is considered appropriate for pinnipeds, which tend to be less responsive than many cetaceans.

Hearing Impairment and Other Physical Effects

Temporary or permanent hearing impairment is a possibility when marine mammals are exposed to very strong sounds, but there has been no specific documentation of this for marine mammals exposed to sequences of airgun pulses. Current NMFS policy regarding exposure of marine mammals to high-level sounds is that cetaceans and pinnipeds should not be exposed to impulsive sounds ≥180 and ≥190 dB re 1 µPa (rms), respectively (NMFS 2000). Those criteria have been used in defining the safety (shut down) radii planned for the proposed seismic survey. However, those criteria were established before there were any data on the minimum received levels of sounds necessary to cause temporary auditory impairment in marine mammals. As discussed in Appendix C, Section 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.

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. NMFS has indicated that it may issue new noise exposure criteria for marine mammals that account for the now-available scientific data. 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 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 Section XI). 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). 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.

A detailed overview of current available information is provided in Appendix C to this application. Overall, based on current knowledge and implementation of mitigation measures as described, there is little potential for baleen whales, odontocetes and pinnipeds that show avoidance of operating 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 that PTS might 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).

Permanent Threshold Shift (PTS)

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

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

In the proposed project, marine mammals are unlikely to be exposed to received levels of seismic pulses strong enough to cause more than slight TTS. Given the higher level of sound necessary to cause PTS, it is even less likely that PTS could occur. 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 the case during the proposed project where the airgun configuration focuses most energy downward, the ship is moving at 4–5 knots, and most animals are migrating southward.

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

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 to the species occurring in the project area even in the case of large airgun arrays. Appendix C, Section 6.3 provides additional details.

2. POTENTIAL EFFECTS OF PINGER SIGNALS

A pinger system (DigiRANGE II) will be used during seismic operations to position the airgun array and hydrophone streamer relative to the vessel. Sounds from the pingers are very short pulses, occurring for 10 ms, with source level ~180 dB re 1 µPa·m at 55 kHz, ~188 dB re µPa·m at 75 kHz, and ~184 dB re 1 µPa·m at 95 kHz. One pulse is emitted on command from the operator aboard the source vessel, which under normal operating conditions is once every ~10 s. Most of the energy in the sound pulses emitted by this pinger is at very high frequencies between 50 and 100 kHz. The signal is omnidirectional.

The pinger produces sounds that are above the range of frequencies produced or heard by many of the marine mammals expected to occur in the study area. However, the beluga whale produces echolocation sounds (clicks) within the 50–100 kHz range (Au et al. 1985, 1987; Au 1993), and belugas have good hearing sensitivity across this ultrasonic frequency band (White et al. 1978; Johnson et al. 1989). In the event that killer whales or harbor porpoises are encountered, they could also hear the pinger signals. Some seals also can hear sounds at frequencies up to somewhat above 55 kHz (See §8.2 *in* Richardson et al. [1995] for a review of cetacean and pinniped hearing capabilities). Neither baleen whales nor walruses would hear sounds at and above 55 kHz (for walrus, see Kastelein et al. 2002).

Masking

The pinger produces sounds within the frequency range used by belugas and other odontocetes that may be present in the survey area. Some seals also can hear sounds at frequencies up to somewhat above 55 kHz. (See §8.2 *in* Richardson et al. [1995] for a review of cetacean and pinniped hearing capabilities.) However, marine mammal communications will not be masked appreciably by the pinger signals. This is a consequence of the relatively low power output, low duty cycle, and brief period when an individual mammal is likely to be within the area of potential effects. Also, in the case of seals, the pulses do not overlap with the predominant frequencies in the calls, which would avoid significant masking. Baleen whales would not hear sounds at and above 55 kHz so the pinger would have no effect on them.

Behavioral Responses

Marine mammal behavioral reactions to other pulsed sound sources are discussed above, and responses to the pinger are likely to be similar to those for other pulsed sources if received at the same levels. However, the pulsed signals from the pinger are much weaker than those from the airgun. Therefore, behavioral responses are not expected unless marine mammals are very close to the source. In this project, odontocetes and seals are the types of marine mammals that might hear the pings if these animals were close to the source. The maximum reaction that might be expected would be a startle reaction or other short-term response. NMFS (2001) has concluded that momentary behavioral reactions “do not rise to the level of taking”.

Hearing Impairment and Other Physical Effects

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

VIII. ANTICIPATED IMPACT ON SUBSISTENCE

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

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

1. 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. There is little or no bowhead hunting by the community of Point Lay, so beluga and walrus hunting are of more importance there. Members of the Wainwright community hunt bowhead whales in the spring, although bowhead whale hunting conditions there are often more difficult than elsewhere, and they do not hunt bowheads during seasons when Statoil's seismic operation would occur. Depending on the level of success during the spring bowhead hunt, Wainwright residents may be very dependent on the presence of belugas in a nearby lagoon system during July and August. Barrow residents focus hunting efforts on bowhead whales during the spring and generally do not hunt beluga then (Table 8). However, Barrow residents also hunt in the fall, when Statoil expects to be conducting seismic surveys (though not near Barrow).

Bowhead whale hunting is a key activity in the subsistence economies of northwest Arctic communities. The whale harvests have a great influence on social relations by strengthening the sense of Inupiat culture and heritage in addition to reinforcing family and community ties.

An overall quota system for the hunting of bowhead whales was established by the International Whaling Commission in 1977. The quota is now regulated through an agreement between NMFS and the Alaska Eskimo Whaling Commission (AEWC). The AEWC allots the number of bowhead whales that each whaling community may harvest annually (USDI/BLM 2005). The annual take of bowhead whales has varied due to (a) changes in the allowable quota level and (b) year-to-year variability in ice and weather conditions, which strongly influence the success of the hunt.

Bowhead whales migrate around northern Alaska twice each year, during the spring and autumn, and are hunted in both seasons. Bowhead whales are hunted from Barrow during the spring and the fall migration and animals are not successfully harvested every year (Table 8). The spring hunt there and at Barrow occurs after leads open due to the deterioration of pack ice; the spring hunt typically occurs from early April until the first week of June. The fall migration of bowhead whales that summer in the eastern Beaufort Sea typically begins in late August or September. Fall migration into Alaskan waters is primarily during September and October.

In the fall, subsistence hunters use aluminum or fiberglass boats with outboards. Hunters prefer to take bowheads close to shore to avoid a long tow during which the meat can spoil, but Braund and Moorehead (1995) report that crews may (rarely) pursue whales as far as 50 mi (80 km). The autumn bowhead hunt usually begins in Barrow in mid-September, and mainly occurs in the waters east and northeast of Point Barrow.

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 planned mobilization and start date for seismic surveys in the Chukchi Sea (~20 July and ~1 August) is well after the end of the spring bowhead migration and hunt at Wainwright and Barrow. Seismic operations will be conducted far offshore from Barrow and are not expected to conflict with subsistence hunting activities. Specific concerns of the Barrow whaling captains will be addressed as part of the Plan of Cooperation / Conflict Avoidance Agreement that is being negotiated with the AEWC (see Section XII, below).

TABLE 8. Bowhead landings at Wainwright 1993–2004 and Barrow 1993–2008. Wainwright numbers are from spring surveys, the 2002 and 2003 data were missing. Numbers compiled in USDI/BLM (2003) from various sources. Barrow numbers provide "total landings (autumn landings)". From Burns et al. (1993), various issues of IWC Reports, AEWC, J.C. George (NSB Dep. Wildl. Manage.) and EDAW/AECOM 2007.

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

Beluga whales are available to subsistence hunters along the coast of Alaska in the spring when pack-ice conditions deteriorate and leads open up. Belugas may remain in coastal areas or lagoons through June and sometimes into July and August. The community of Point Lay is heavily dependent on the hunting of belugas in Kasegaluk Lagoon for subsistence meat. From 1983–1992 the average annual harvest was ~40 whales (Fuller and George 1997). In Wainwright and Barrow, 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; Table 9). The seismic survey activities take place well offshore, far away from areas that are used for beluga hunting by the Chukchi Sea communities. It is possible, but unlikely, that accessibility to belugas during the subsistence hunt could be impaired during the survey.

Ringed seals are hunted mainly from October through June. Hunting for these smaller mammals is concentrated during winter because bowhead whales, bearded seals and caribou are available through other seasons. In winter, leads and cracks in the ice off points of land and along the barrier islands are used for hunting ringed seals. The average annual ringed seal harvests by the various communities are presented in Table 9. 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.

The ***spotted seal*** subsistence hunt peaks in July and August along the shore where the seals haul out, but usually involves relatively few animals (Table 9). Spotted seals typically migrate south by October to overwinter in the Bering Sea. During the fall migration spotted seals are hunted by the Wainright and Point Lay communities as the seals move south along the coast (USDI/BLM 2003). 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 seismic survey will remain offshore of the coastal harvest area of these seals and should not conflict with harvest activities.

Bearded seals, although generally not favored for their meat, are important to subsistence activities in Barrow and Wainright, 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 spring and summer months in the Chukchi Sea (USDI/BLM 2003, 2005; Table 9). The animals inhabit the environment around the ice floes in the drifting nearshore ice pack, so hunting usually occurs from boats in the drift ice. Most bearded seals are harvested in coastal areas inshore of the proposed survey so no conflicts with the harvest of bearded seals are expected. Issues relating to ***polar bears*** and walruses are being addressed by ongoing coordination between Statoil and USFWS. However, for completeness, concerns about interactions with subsistence hunting of these two species are summarized briefly here.

The USFWS has monitored the harvest of polar bears in Alaska using a mandatory marking, tagging, and reporting program implemented in 1988. Polar bears are harvested in the winter and spring, but comprise a small percent of the annual subsistence harvest. The USFWS estimated that, from 1995 to 2000, the average annual harvest of the Southern Beaufort Sea polar bear stock in Alaska was 32 (Angliss and Lodge 2004). That includes harvests at all coastal communities. It is not expected that the seismic survey will interfere with polar bear subsistence hunting due to the limited annual harvest documented by USFWS and the fact that the subsistence hunt typically takes place in the winter and spring, either well after or well before the scheduled survey.

Walruses are hunted primarily from June through mid-August in Chukchi waters to the west of Point Barrow and southwest to Peard Bay. The harvest effort peaks in July–August and is often conducted at the same time as the hunting of bearded seals. The annual walrus harvest by Barrow residents ranged from 7 to 206 animals from 1990 to 2002, and ranged from 0 to 4, and 0 to 153 for the Point Lay and Wainwright communities, respectively (Fuller and George 1997; USDI/BLM 2003, 2005). It is possible, but unlikely, that accessibility to walruses during the subsistence hunt could be impaired during seismic surveys in the Chukchi Sea. However, the seismic survey will not be conducted within the polynya zone where marine mammal migrate during the spring, designated by the southeastern border of the MMS lease sale area 193.

TABLE 9. Average[a] annual take of marine mammals other than bowhead whales harvested by the communities of Point Lay, Wainwright, and Barrow.

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

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

In the event that both marine mammals and hunters are near the 3D survey area when seismic surveys are in progress, the proposed project potentially could impact the availability of marine mammals for harvest in a small area immediately around the vessel, in the case of pinnipeds, and possibly in a large area in the case of migrating bowheads. However, the majority of marine mammals are taken by hunters within ~21 mi (~33 km) from shore (Figure 2), and the seismic source vessel M/V *Geo Celtic* will remain far offshore, well outside the hunting areas. Considering the timing and location of the proposed seismic survey activities, as described in Section I and II, the proposed project is not expected to have any significant impacts to the availability of marine mammals for subsistence harvest. Specific concerns of the respective communities will be addressed as part of the Plan of Cooperation that is being negotiated with the AEWC (see Section XII, below).

2. 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 seismic survey is planned.

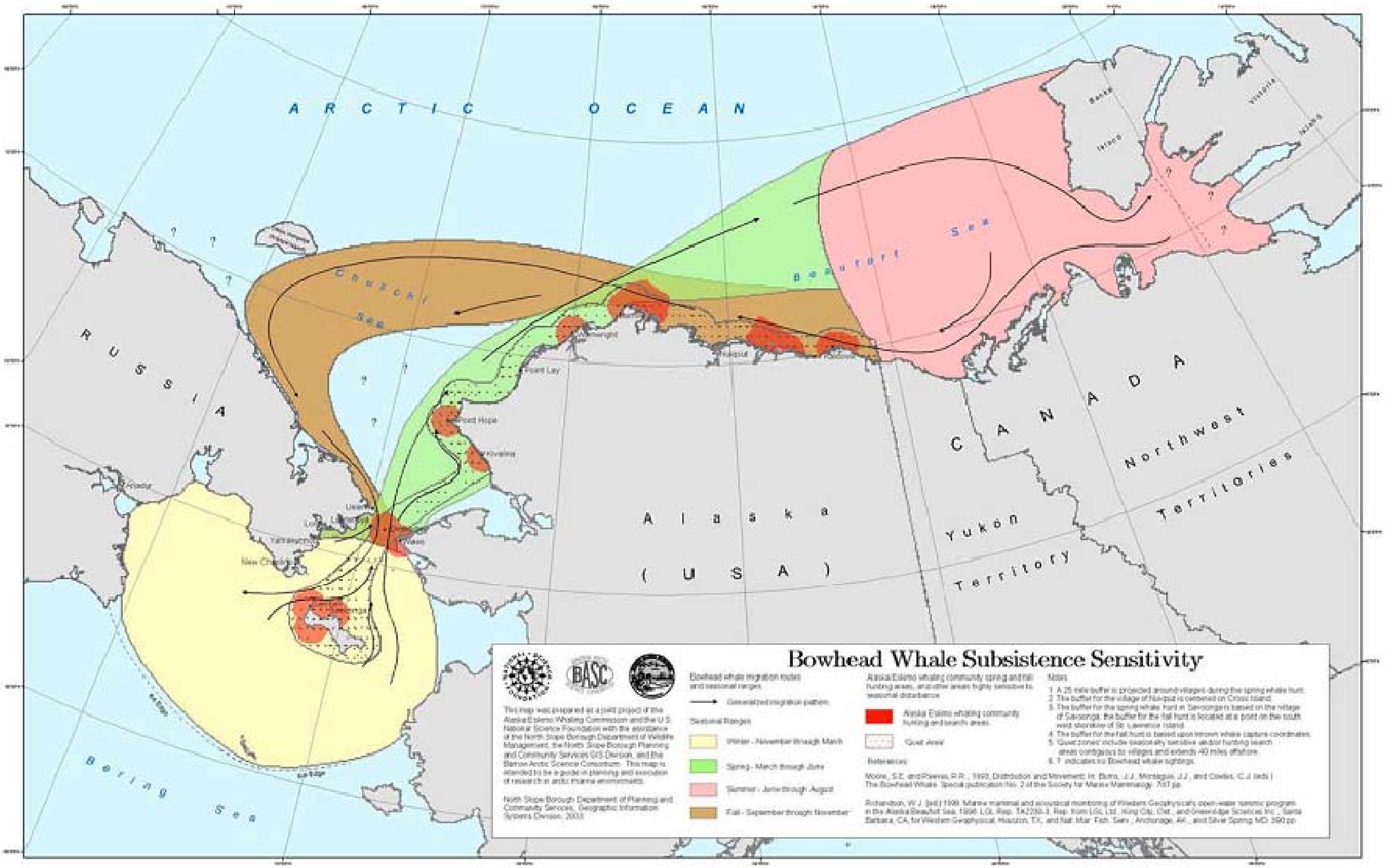

FIGURE 2. Bowhead migration routes and seasonal ranges. Yellow represents the winter breeding area, green the spring migration route, pink summer feeding area and brown fall migration route. Red areas show the extent of hunting areas of the Alaska Eskimo whaling communities (NSF 2004).

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 Section VI and VII, above.

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, and thus to areas well away from the nearshore waters where most subsistence fishing activities occur.

The only designated Essential Fish Habitat (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. No EFH species will be present as very early life stages when they would be unable to avoid seismic exposure that could otherwise result in minimal mortality.

The proposed Chukchi Sea seismic program for 2010 is predicted to have negligible to low physical effect 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.

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). However, by the time most bowhead whales reach the Chukchi Sea (October), they will likely no longer be feeding, or if it occurs it will be very limited. 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.

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.

The introduction of pulsed sounds generated by seismic airguns is the main source of potential impacts on marine mammal species and the focus of this request. The response of the animal depends on various factors, but most likely short term behavioral responses would occur. No lethal injuries are expected. Implementation of the mitigation measures as described below will reduce the potential impacts to marine mammals. This section describes the measures that have been implemented in the survey design of the proposed survey and those that will be implemented during the survey.

1. MITIGATION MEASURES WITHIN THE SURVEY DESIGN

Mitigation measures to reduce any potential impact on marine mammal species that have been considered and implemented in the planning and design phase of the proposed survey are as follows:

- The total discharge volume to be used has been kept as low as possible without compromising data quality. The total volume for the proposed survey is 3,000 in^3.
- The airgun array includes 10 more airguns than required for the survey. These extra airguns are intended to be used as spares to facilitate a more effective operation (and as such, with all other factors being equal, a reduction in total field time).

- Considering the shallow water depth of the survey area, an unusual large streamer array with 12 individual streamers will be used. The advantage of a wider streamer array is that it allows for an increasing separation distance between source lines and as such reduces the number lines and shotpoints needed to acquire the 3D seismic data in the survey area. A reduction in number of source lines also reduces the total survey time (again, with all other factors that can influence the survey duration being equal).

2. MITIGATION MEASURES DURING OPERATION

The mitigation measures to be implemented during the proposed survey that are summarized in this section are based on NMFS requirements from most recent similar surveys.

The seismic survey will take place in Statoil's lease area in the Chukchi Sea in water depths ranging from 98–164 ft (30–50 m). This area is located in the main fall migration path of the bowhead whales and close to Hanna Shoal, which is an ecologically important area. The total acquisition time will be ~60 days, starting early August, weather depending. Due to the large distance from shore and from known hunting areas, the intention is to continue seismic data acquisition during the fall bowhead hunt. Specific concerns of the respective communities will be discussed and addressed as part of the Plan of Cooperation process. Other cetacean species that can be expected in the area during the survey are beluga whale, gray whale, and harbor porpoise. Also, the spotted, ringed, and bearded seal can be encountered in the area. The Pacific walrus and polar bear are not part of this application. With the proposed mitigation measures (see below), any effect on individuals are expected to be limited to short term behavioral disturbance.

The mitigation measures are an integral part of the survey in the form of specific procedures, such as: i) establishment and monitoring of safety zones; ii) speed and course alterations; iii) power down, ramp up and shut down procedures, and iv) provisions for poor visibility conditions. For the implementation of these measures it is important to first establish and verify the distances of various received levels that function as safety zones and second to monitor these safety zones and implement mitigation measures as required. In addition, their will be specific procedures for marine mammal carcasses that might be encountered during the survey.

Establishment and Monitoring of Safety Zones

Greeneridge Sciences, Inc. estimated for Statoil the distances where sound levels from the 3000 in^3 airgun array and 60 in^3 mitigation gun would reach 190, 180, 160, and 120 dB re 1 µPa rms. The basis for these estimations is the results from sound source verification measurements of similar size airgun arrays in the Chukchi Sea (Section VI, Table 4). The pre-season estimates of distances to 190, 180, and 160 dB re 1 µPa rms will be used as safety radii for the implementation of mitigation measures as described below before distances based on field measurements have become available. The distances to received sound levels of ≥160 dB form the basis for estimating the number of animals potentially affected (Section VI, Table 6, 7).

Prior to the start of seismic data acquisition, received sound levels to 190, 180, 160 and 120 dB re 1 µPa rms will be measured as a function of distance from the array. This will be done for: a) the 3000 in^3 airgun array, and b) one 60 in^3 gun (smallest gun in the array). Based on the results from the field measurements, the pre-season safety radii will be adapted where applicable.

Marine mammal observers on board of the vessels play a key role in the monitoring of these safety zones and in the implementation of mitigation measures. Their primary role is to monitor for the presence of marine mammals during all daylight airgun operations and during any nighttime start-up of the airguns. These observations will provide the data needed to implement the key mitigation measures as described below. When marine mammals are observed within, or about to enter, designated safety zones airgun operations will immediately be powered down (or shut down if necessary). The safety zones to prevent any hearing impairment are defined as the distance from the source to a received level of ≥190 dB for pinnipeds and ≥180 dB for cetaceans. A specific procedure to detect aggregations of baleen whales (12 or more) within the ≥160 dB zone will also be implemented. Monitoring of the presences of 4 or more bowhead whale cow-calf pairs within the ≥120 dB zone is not required by NMFS in the Chukchi Sea due to practical and safety considerations.

Speed and Course Alterations

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, changes of the vessel's speed and/or direct course should be considered if this does not compromise operational safety. For marine seismic surveys using large streamer arrays, course alterations are practically not really possible. 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., power down or shut down of the airgun(s).

Power Down, Ramp Up and Shut Down Procedures

Power down, ramp up and shut down procedures are implemented to prevent marine mammals from exposure to received levels of ≥190 dB (pinnipeds) and ≥180 dB (cetaceans). Dedicated marine mammal observers monitor these safety zones and have the authority to call for the implementation of these procedures when required by the situation. Power down, ramp up and shut down procedures are also implemented for baleen whale aggregations exposed to received pulsed sound levels of ≥160 dB to limit potential behavioral disturbance. A summary of these situations is described below for each procedure. The criteria are consistent with guidelines listed for cetaceans and pinnipeds by NMFS (2000), and other guidance by NMFS.

Power Down Procedure

A power down involves decreasing the number of operating airguns such that the radii of the 190 dB, 180 dB and 160 dB zones are decreased to the extent that observed marine mammals are not in the applicable safety zone. Situations that would require a power down are listed below.

- When the vessel is changing from one source line to another, one airgun or a reduced number of airguns is operated. The continued operation of one airgun or a reduced airgun array 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.

- If a marine mammal or aggregation of baleen whales 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 the animal from entering the safety zone. As an alternative to a complete shut down, the airguns may be powered down before the animal is within the safety zone.
- If a marine mammal or aggregation of baleen whales is already within the safety zone when first detected, the airguns may be powered down immediately if this is a reasonable alternative to a complete shut down. This decision will be made by the MMO and can be based on the results obtained from the acoustic measurements for the establishments of safety zones (see Section 11.2.1).

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

Shut Down Procedures

A shut down procedure involves the complete turn off of all airguns. Ramp up procedures will be followed during resumption of full seismic operations. The operating airgun(s) will be shut down completely during the following situations:

- If a marine mammal or aggregation of baleen whales approaches or enters the applicable safety zone and a power down is not practical or adequate to reduce exposure to less than 190, 180 or 160 dB rms, as appropriate.
- If a marine mammal or aggregation of baleen whales approaches or enters the estimated safety radius around the reduced source or smallest gun used during a power down.

Airgun activity will not resume until the marine mammal or aggregation of baleen whales has cleared the safety radius. The animal will be considered to have cleared the safety radius as described above under power down procedures.

Ramp Up Procedures

A ramp up procedure will be followed when the airgun array begins operating after a specified duration with no or reduced airgun operations. The specified duration depends on the speed of the source vessel, the size of the airgun array that is being used, and the size of the safety zone, 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 the smallest airgun, 60 in^3. The precise ramp up procedure has yet to be determined, but Statoil intends to follow the ramp up guideline of no more than 6 dB per 5-min period (unless otherwise required). 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 26-airgun array will be maintained. A ramp up procedure can be applied only in the following situations:

- If, after a complete shut down, the entire 180 dB safety zone has been visible for at least 30 min prior to the planned start of the ramp up in either daylight or nighttime. If the entire safety zone is visible with vessel lights and/or night vision devices, then ramp 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 either be alerted by the sounds from the single airgun and could move away, or may be detected by visual observations.
- If no marine mammals have been sighted within or near the applicable safety zone during the previous 15 min in either daylight or nighttime, provided that the entire safety zone was visible for at least 30 min.

Poor Visibility Conditions

Statoil plans to conduct 24-hrs operations. Regarding night time observations, note that there will be no periods of total darkness until late August. Observers dedicated to marine mammal 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) and will call for the airguns to be shut down if marine mammals are observed in or about to enter the safety zones. If a ramp up procedure needs to be conducted during nighttime, two marine mammal observers need to be present to monitor marine mammals near the source vessel and to determine if the proper conditions are being met for a ramp up. The proposed provisions associated with operations at night or in periods of poor visibility include the following:

- If during foggy conditions or darkness (which may be encountered starting in late August), the full 180 dB rms safety zone is not visible, the airguns can not commence a ramp up procedure from a full shut down.
- If one or more airguns have been operational before nightfall or before the onset of foggy conditions, they can remain operational throughout the night or foggy conditions. In this case ramp up procedures can be initiated, even though the entire safety radius may not be visible, on the assumption that marine mammals will be alerted by the sounds from the single airgun and have moved away.

Statoil has considered the use of a towed passive acoustic monitoring array (PAM) to allow detection of marine mammals during night time and poor visibility conditions, such as fog. For that reason Statoil and its contractors attended the MMS workshop in Boston on 17-19 November on status and applications for acoustic monitoring of marine mammals. It appears that available towed PAM arrays still have too many limitations to be relied upon as a mitigation tool as part of the operations. This is especially the case in the Chukchi and Beaufort Sea where the main species of interest is the bowhead whale, a low frequency caller. Statoil therefore decided not to use towed PAM arrays as a mitigation tool for low visibility conditions.

Marine Mammal Carcasses

If an injured or dead marine mammal is sighted within an area where airguns were operating within the past 24 hours, the array will be shut down immediately; given that the carcasses appearance indicates that the animal has been dead for a lesser period. Activities can resume after the lead MMO (to the best of his/her abilities) determined that injury resulted from something other than airgun operations. After written certification, including supporting documents (e.g., photographs or other evidence) has been prepared by the MMO, the operations will resume. Within 24 hours after the event the operator will notify NMFS and provide them with the written documentation.

If the cause of the injury or death cannot be immediately determined by the lead MMO, the incident will be reported immediately to either the NMFS Office of Protected Resources or the NMFS Alaska Regional Office. The seismic airgun array shall not be restarted until NMFS is able to review the circumstances, make determination as to whether modifications to the activities are appropriate and necessary, and has notified the operator that activities may be resumed.

In all cases, the Alaska Region of the Marine Mammal Stranding Network (ph. 1-800-853-1964) will be notified no later than 24 hours after the sighting.

XII. PLAN OF COOPERATION

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

(i) A statement that the applicant has notified and provided the affected subsistence community with a draft plan of cooperation;
(ii) A schedule for meeting with the affected subsistence communities to discuss proposed activities and to resolve potential conflicts regarding any aspects of either the operation or the plan of cooperation;
(iii) A description of what measures the applicant has taken and/or will take to ensure that proposed activities will not interfere with subsistence whaling or sealing; and
(iv) What plans the applicant has to continue to meet with the affected communities, both prior to and while conducting activity, to resolve conflicts and to notify the communities of any changes in the operation.

Statoil intends to maintain an open and transparent process with all stakeholders throughout the life-cycle of activities in the Chukchi Sea. Statoil began the stakeholder engagement process in 2009 with meeting Chukchi Sea community leaders at the tribal, city, and corporate level. Statoil will continue to engage with leaders, community members, and subsistence groups, as well as local, state, and federal regulatory agencies throughout the exploration and development process.

As part of stakeholder engagement, Statoil is developing a Plan of Cooperation (POC) for the proposed 2010 seismic acquisition. The POC summarizes the actions Statoil will take to identify important subsistence activities, inform subsistence users of the proposed survey activities, and obtain feedback from subsistence users regarding how to promote cooperation between subsistence activities and the Statoil program.

A POC is required to comply with OCS Lease Sale 193 stipulations (Stipulation No. 5) and federal regulatory requirements [50 CFR 216.104(a)(12)ii)]. The POC also fulfills the requirements of three major federal permits: the National Marine Fisheries Service (NMFS) Incidental Harassment Authorization, the U.S. Fish and Wildlife Service (USFWS) Letter of Authorization, and the MMS Geophysical and Geological permit.

Statoil met with leaders from the communities of Barrow, Wainwright, Point Lay, Point Hope, and Kotzebue during the last week of October/first week of November 2009, in small groups and on a one-on-one basis. These meeting enabled Statoil to introduce themselves and the planned 2010 marine seismic acquisition program to community leaders and to discuss local concerns regarding subsistence activities, timing of operations, discharge, and local hire/workforce development.

Based upon these meetings, a draft POC document is being developed. Upon completion, the draft POC will be submitted to each of the community leaders Statoil visited during the October/November Leadership Meetings as well as a few other community members. Statoil will also submit the draft POC to NMFS, USFWS, and MMS as part of the permit application packets. Public POC meetings will be held in January in the communities of Barrow, Point Hope, Point Lay, and Wainwright to obtain input from the general public and individual subsistence hunters within these communities.

A final POC that documents all consultations with community leaders, subsistence users groups, individual subsistence users, and community members will be submitted to NMFS, USFWS, and MMS upon completion of consultation. The final POC will include feedback from the Leadership Meetings and POC meetings. Statoil will continue to document all consultation with the communities and subsistence stakeholders.

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...*

Statoil proposes to sponsor marine mammal and acoustic monitoring during the present project, in order to implement the proposed mitigation measures, to satisfy the anticipated monitoring requirements of the USFWS LoA and NMFS IHA, and to meet any monitoring requirements agreed to as part of the Plan of Cooperation.

Statoil's proposed Monitoring Plan is described below and in more detail in the supplemental Marine Mammal Monitoring and Mitigation Plan submitted along with this application. Statoil understands that this Monitoring Plan will be subject to review by NMFS and others, and that refinements may be required. Statoil 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. Statoil has agreed to work with Shell and ConocoPhillips to collect baseline data on and near the Chukchi Sea lease holdings of the three companies, including oceanographic data, benthic and epi-bethic communities, fish, marine mammals, and marine birds.

1. VESSEL-BASED VISUAL MONITORING

Vessel-based marine mammal observers (MMOs) will monitor for the presence of marine mammals in the project area during all daytime hours and during any ramp ups of the airgun(s) at night. MMOs will be appointed by Statoil with NMFS and USFWS concurrence. At least one Alaska Native resident knowledgeable about the marine mammals of the area is expected to be included as part of the MMO team on board the source vessel and chase/monitoring vessels. The main purpose of the MMOs is to monitor the established safety zones and to implement the mitigation measures as described in Section XI. The objectives of the vessel based marine mammal monitoring are as follows:

1. To form the basis for implementation of mitigation measures during the seismic operation (e.g., airgun power-down, shut-down and ramp-up);
2. To obtain information needed to estimate the number of marine mammals potentially exposed to 160 dB re 1μPa, which must be reported to NMFS within 90 days after the survey;
3. To compare the distance and distribution of marine mammals relative to the source vessel at times with and without seismic activity;
4. To obtain data on the behavior and movement patterns of marine mammals observed and compare those at times with and without seismic activity

Marine Mammal Observer Protocol

During seismic operations when there is 24 hrs of daylight, five observers will be based aboard the seismic source vessel and at least three MMOs on the chase/monitoring vessels. As the number of hours of daylight decreases in the fall, the number of MMOs on the source vessel might be reduced. During periods of 24 hrs of daylight, having 5 observers aboard the source vessel will allow 2 observers to be on duty at all times, if required. Observers will monitor for the presence of marine mammals near the seismic vessel during ongoing daytime operations and any nighttime start ups of the airguns (note that there will be no periods of total darkness until late August). MMOs will normally be on duty in shifts of no longer than 4 hours. Prior to their mobilization, all MMOs will receive a survey specific training. They will also be provided with a marine mammal observers manual that includes a detailed observer protocol and summarizes all procedures to be followed to implement the mitigation measures according to stipulations in the IHA and LoA permits.

Once on board and before the start of the seismic survey, the lead MMO will explain the crew of the seismic source vessel about the function of the MMOs, their monitoring protocol and mitigation measures to be implemented. Additional information will be provided to the crew by the lead MMO that will allow the crew to assist in the detection of marine mammals and (where possible and practical) in the implementation of mitigation measures.

The M/V *Geo Celtic* and the two chase/monitoring vessels are a suitable platform for marine mammal observations. Observations will be made from either the bridge or the flying bridge, which are ~66 ft (~20 m) above sea level for the source vessel. During daytime, the MMO(s) will scan the area around the vessel systematically with reticle binoculars (e.g., 7×50 Fujinon), and with the naked eye. Fujinon 25×150 “Big-Eye” binoculars will be mounted on the bridge wing or flying bridge of the *Geo Celtic* and will be used by observers during good weather conditions. Night vision equipment (Generation 3 binocular-image intensifier or equivalent) will be available to MMOs for assisting in any monitoring during darkness. Laser rangefinding binoculars will be available to assist with distance estimation; these are useful in training observers to estimate distances visually, but are generally not useful in measuring distances to animals directly.

Communication Procedures

When marine mammals in the water are detected within or about to enter the designated safety radius, the airgun(s) will be powered down or shut down immediately. To assure prompt implementation of shut downs, multiple channels of communication between the MMOs and the airgun technicians will be established. During power downs and shut downs, the MMO(s) will continue to maintain watch to determine when the animal(s) are outside the safety radius. Airgun operations will not resume until the animal is outside the safety radius. Marine mammals will be considered to have cleared the safety radius if they are visually observed to have left the safety radius, or if they have not been seen within the radius for 15 min (pinnipeds or polar bears) or for 30 min (cetaceans). Direct communication with the airgun operator will be maintained throughout these procedures.

Data Recording

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

2. ACOUSTIC MONITORING

Measurements of received sound levels as a function of distance and direction from the proposed airgun arrays will be made prior to or at the beginning of the seismic survey. Results of the acoustic characterization/verification of the airgun array will be used to refine the pre-season estimates of safety and disturbance radii applicable to the sources during the remainder of seismic operations. A preliminary report of the measurement results concerning (at minimum) the 190 dB, 180 dB and 160 dB (rms) safety radii will be submitted to NMFS within 120 hrs after the measurements are completed.

Information on the acoustic footprint of Statoil’s seismic survey program will be obtained through the deployment of bottom mounted autonomous acoustic recorders. Statoil has participated in the acoustic monitoring program in cooperation with Shell and ConocoPhilips and is planning to continue this cooperation in 2010. The main objectives for Statoil are: 1) to understand the propagation and attenuation of the seismic sounds in the waters surrounding the project area, 2) to determine the ambient sound levels in the waters surrounding the project area, where possible, and 3) assess the effects of sound on marine mammals occurring in the project area (specifically migrating bowhead whales), insofar the collected marine mammal data allows.

3. AERIAL SURVEYS

Statoil does not anticipate to conduct aerial surveys as part of the mitigation and monitoring program for Chukchi Sea seismic activities. Aerial surveys would be impractical and unsafe due to the location of the survey area ~150 mi (240 km) offshore.

4. REPORTING

During the field season, brief progress reports will be provided to NMFS if called for by the IHA, on the schedule specified in the IHA.

A report on the preliminary results of the acoustic verification measurements, including as a minimum the measured 190, 180 and 160 dB (rms) radii of the airgun sources, will be submitted within 120 hrs of the completion of the measurements. This report will specify the refinements to the safety radii that are proposed for adoption.

A report on Statoil’s 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, the measured sound levels, 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, shut downs, and other mitigation actions will be reported. 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.

Provided that an acceptable methodology and business relationship can be worked out in advance, Statoil will cooperate with any number of external entities, including other energy companies, agencies, universities, and NGOs, in its efforts to manage, understand, and fully communicate information about environmental impacts related to the seismic activities.

In 2009 Statoil has participated in the COMIDA surveys in 2009 and is currently in discussion with other operators to enter into a similar cooperation for 2010 insofar applicable and possible. The studies in which Statoil participated in 2009 included: 1) benthic and sediment sampling as part of the program "Impact Assessment Study at Historical Exploratory Drilling Locations in the Chukchi Sea", 2) demersal and small pelagic fish sampling as part of the program "Distribution, Abundance, and Feeding Ecology of Arctic Marine Fishes in the Northeastern Chukchi Sea", and 3) deployment of bottom mounted acoustic recorders in the offshore Chukchi Sea as described in the previous section. Participation in the COMIDA surveys is not directly related to the proposed seismic survey. However, gathering environmental data is important for Statoil in order to gain knowledge about potential environmental impacts from their operations.

Statoil is also interested in better understanding cumulative effects. Statoil recognizes that the challenge lies in determining a responsible approach to considering cumulative effects from sound. However, we are open to ideas and discussions with regard to the assessment of cumulative effects from sound and are open to cooperation with others on initiatives that address this issue.

Statoil is a member of the OGP E&P Sound & Marine Life joint industry programme (JIP), which is an international consortium of oil and gas companies organized under the OGP in London. The objective of the JIP program is to obtain scientifically valid data on the effects of sounds produced by the E&P industry on marine life. More information can be found at the JIP website on http://www.soundandmarinelife.org/.

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APPENDIX A:
VESSEL SPECIFICATIONS

M/V GEO CELTIC

TECHNICAL SPECIFICATIONS

CONTENTS

1. VESSEL

1.1. VESSEL GENERAL

Name	M/V Geo Celtic
Operator	Fugro-Geoteam AS
Owner	E Forland AS
Seismic Management	Fugro Norway Marine Services AS
Maritime Management	E Forland AS
Type	3D seismic survey vessel
Port of registration	Bergen, Norway
Flag	Norwegian
Class	DNV = 1A1 ICE-C SF COMF-V(3)C(3) HELDK-SH RP E0 CLEAN DK
Class registration no.	D26988
Call sign	LAKF6
IMO	9376995
MMSI	258966000
Year built/rebuilt	2006/2007
Length overall	100.80 m
Breadth moulded	24 m
Breadth maximum	28 m
Draught, loaded	7.5 m
Tonnage	12109 gross tons, 3633 net tons
Cruising speed	16.0 knots
Operation range	World wide
Endurance seismic days max load	60 days
Main engine	4 x generating set continues engine rating MCR 3780 kW 750 RPM (660 V, 3-phase, 60 Hz)
Gearbox	2 x reduction gear boxes, low noise type for driving C.P. propellers
Propulsion	2 x C.P. propellers of low noise design. Fixed nozzle
Rudder	2 x free hanging type with rope-guard fitted in lower end
Steering gear	2 x Rolls-Royce
Azimuth thruster	1 x retractable, 1500kW with complete electric AC drive
Bow thrusters	1 x fixed pitch, 1200 kW with complete electric AC drive.
Stern thruster	None
Main engine monitoring	Kongsberg-Simrad IAS
Electrical power	690V 60 Hz 3ph, 220V 50 Hz 1ph
Emergency generator	1 x 575 kW
Clean power	100 kW UPS
Fuel capacity	HFO capacity 1825 m^3
Fuel consumption	40 tons per day
Fresh water capacity	257 m^3
Fresh water consumption	15 tons per day
Fresh water generator	2 off FW generators with capacity 15 ton/day
Sewage treatment plant	Yes; for 69 persons
Incinerator	Yes; for 69 persons
Black water	Holding tank cap 32 m^3

Grey water	Holding tank cap 29 m^3
Bilge water	Bilge water separator with 3 m^3/h capacity
Sludge	Holding tank cap 33 m^3
Dirty oil	Holding tank cap 13 m^3
Stabilising system	2 off passive anti-rolling tanks
Deck machinery	
Crane	1 x 5 ton SWL, 16 m knuckle arm handling crane on hangar deck aft cl. 1 x 10 ton SWL, 16 m knuckle arm handling crane on hangar deck stb. 1 x 10 ton SWL, 16 m knuckle arm handling crane on hangar deck ps.
Source handling beams	2 x Odim gun booms with el. drive
Streamer winch	5 x Odim double streamer winch with el. drive 2 x Odim double streamer winch with PF: 12T BF 33 outer & el. drive
Lead-in winch	None
Storage winch	5 x Odim storage winch with el. drive
Spread rope winch	4 x Odim with el. drive
Source winch	8 x Odim capacity 800 m cable, el. drive
Wide-tow winch	2 x Odim wide tow winch 60 ton pulling
Auxiliary winch	5 x Auxiliary winches with el. drive
Drum handling	Electric/hydraulic drum spooling rack
Tow points	12 towing points with blocks
Wide tow shock absorbers	2 x Vestdavit 160 ton
Paravane	Barovane 48
Paravane handling	Odim handling davit
Transverse towing point	2 x Odim 5 ton winches
Hydraulic power pack	Dimo 2 x 305 l/min @ 250 bar
Accommodation	For 69 persons+hospital. All cabins with separate toilets/showers. Some cabins with radio/cd player and some with IMac CD/DVD player
Galley store	Facilities for 70 persons
Mess	Seating for 60 persons
Day rooms	Lounges for smokers and non-smokers with seating for 65 persons
Exercise room	Large exercise room with saunas
Air condition	Air condition with chilled water system for world wide conditions
Helicopter landing zone	Dimensioned and arranged for the operation of Sikorsky S61 helicopters. Deck to be arranged and equipped according to CAA rules CAP 437 / ICAO requirements

1.2. VESSEL NAVIGATION AIDS

Auto pilot	Kongsberg cJoy
DGPS	Furuno
Differential GPS	Furuno
Radar no. 1	Furuno 10 cm ARPA-radar with daylight monitor. Antenna with built-in transmitter
Radar no. 2	Furuno 3 cm ARPA-radar with daylight- and performance monitor. Antenna with built-in transmitter
Gyros	SG Brown Meridian Surveyor with • 1 x digital gyro repeater auto pilot, • 2 x digital gyro repeaters for mounting in bridge wing consoles • 1 x steering repeater • 1 x digital gyro repeater for each steering gear room • 1 x class A magnetic compass • Binnacle, reflector compass, azimuth device, straight vertical reflection tube and hood
Speed log	Furuno DS 80 2-axis doppler log
VHF direction finder	Helicopter beacon
Wind sensor	Seatex 100 HMS
Navigation echo sounder	Furuno FE 700
Electronic chart	TECDIS
Navtex	Furuno
Weather fax	Furuno

1.3. VESSEL COMMUNICATION

GMDSS	Furuno FS-2570 / 1570
Inmarsat C	2 x Furuno
Inmarsat B	Sailor
NorSat	Telenor
M/F and H/F	Furuno
VHF stationary	VHF radio, Icom IC-M401E
VHF portable	VHF radio, Entel HT640
UHF portable	UHF radio, Entel HT780
VHF helicopter communication	1 x VHF/AM 1 x portable VHF/AM with headset
Helicopter non-directional beacon	410 kHz helicopter beacon
Internal communication	PABX telephone system with 120 lines
Telephone numbers	
Inmarsat bridge	+871 600 859066
NorSat bridge	+47 23 25 42 91
NorSat captain office	+47 23 25 42 95
NorSat party chief	+47 23 25 42 92
NorSat client office	+47 23 25 42 97
Fax numbers	
Bridge	+47 23 25 42 90
Internet access via NorSat	
E-mail addresses	
Captain	geoceltic-captain@forlandship.no
Party chief	pc@celtic.fugro.geoteam.no
Client	client1@celtic.fugro.geoteam.no.

1.4. VESSEL SAFETY

Safety manning level	69
Covered lifeboat	2 x 90 persons, one each side
Rescue / FRC	750 Magnum
Workboat / MOB boat	1 MOB boat, fast rescue craft, 7 m long, 200 HP inboard engine and water jet drive. 1 x 9.6 m Westplast workboat, twin water jets, twin streamer winches
Inflatable life rafts	3 x 25 persons
Man overboard life raft	JonBuoy (1 man) with remote release
Survival suits	73 pcs Helly Hansen
Life jackets	73
Life rings	18
Smoke hoods	Draeger "Parat C"
Work vest	Crewsaver 275N
Emergency radios	Jotron TR20
EPIRB	Jotron 45SX
Radar transponders	Jotron Tron SART
Fire detection system	Eltek
Fire pumps	3
Fire suits	4+spares
Halon systems	No
Argonite	Yes
CO2 systems	Yes
Foam deluge system	Yes, in engine room
Lg. portable foam extinguishers	Yes

2. SEISMIC

2.1. SEISMIC RECORDING INSTRUMENT

Type	Sercel Seal, 24 bit digital system
Number of channels	8000
Number of waterbreaks	1 pr. streamer (in HESA Section)
Auxiliary channels	36 channels
Sample rate	¼, ½, 1, 2 and 4 ms
Filters	
Low cut	3 Hz analogue 6 dB/octave plus configurable digital low cut (between 2.5 Hz and 15 Hz @ 6dB/octave). Combined filter slope 12 dB/octave
High cut	Depending on sample rate 0.8 Nyquist @ 370dB/octave linear or min phase
Recording format	SEGD 8058 or 8036
Recording medium	IBM 3592
Raid system	Argus by Profocus
QC system	Argus by Profocus
On-line display	Argus by Profocus
Single channel recorder	Argus by Profocus

2.2. STREAMERS

Type	Sercel Sentinel solid streamer
Length	12 x 6000 m Max 1000 channels pr. streamer @ 2ms sampling
Available group interval	12.5 m
Section length	150 m
Groups pr. section	12
Hydrophone type	Sercel Flexible Hydrophone
No. of hydrophones/group	8
Streamer diameter	59.5mm
Streamer sensitivity	19.73 V/Bar @ 22°C
Fault locator	Sercel Seal Digital System
Compasses	ION Model 5011 Compass Bird
Streamer control	ION DigiFIN ION Model 5011 Compass Bird
Acoustics	ION DigiRANGE II

2.3. ENERGY SOURCE

Type	Sodera G-Gun
Size of guns	Up to 250 cu. inch
Typical volume	Single source up to 9000 cu. inch Dual source up to 5100 cu. inch
Maximum output @6 m, 0-206 Hz	
Number of sub-arrays	2 x 3 sub-arrays
Configuration	Single source or dual source
Tow width	Typically 10 m between sub-arrays
Firing control	Seamap GunLink 4000 Digital Gun Controller
QC	Seamap GunLink 4000 Digital Gun Controller
Depth transducers	Seamap Digital, Integrated on GFSM Module
Tow system	Sercel rigid gun floats. Self deflecting
Offset	< 600m from stern of ship
Compressor	3 x LMF high pressure compressor units, each 1700 SCFM
Compressor capacity	48 m^3
Air pressure	138 bar = 2000 psig as well as 207 bar = 3000 psig

2.4. NAVIGATION EQUIPMENT

On-line navigation system	Concept Systems Orca
Primary navigation	Fugro Skyfix-XP DGPS
Demodulator	Fugro 4100LRS
GPS receiver	Fugro SPM2000 with internal Novatel
Secondary navigation	Fugro Starfix.HP DGPS with SPM software
Demodulator	Fugro 4100LRS
GPS receiver	Fugro SPM2000 with internal Novatel
Tailbuoy tracking	Kongsberg Seatex Seatrack 220 RGPS
Gun array tracking	Kongsberg Seatex Seatrack 320 RGPS
Gyro	2 x SG Brown Meridian Surveyor
GPS azimuth	Applanix POS MV 320
Motion sensor	Applanix POS MV 320
Echosounder	Kongsberg Simrad EA600
Echosounder transducers	12, 38, 200 kHz
Acoustic doppler profiler	RDI ADCP Mariner 600kHz type Workhorse
SVP/CTD probe	Valeport Midas SVX2
Moving vessel profiler	Odim MVP300-3400
Streamer mounted speed log	ION Model 7500 Speed Log
Streamer mounted velocity meter	ION Model 7000 Velocimeter
Streamer positioning	ION Model 5011 Compass Bird ION DigiRANGEII acoustics: Up to 180 x CMX unit 2 x CTX transducer flanged - hull 6 x CTX pinger towed - gun
Navigation processing	Concept Systems Sprint Concept Systems NRT
Binning	Concept Systems Reflex

2.5. ONBOARD PROCESSING

Hardware	16 x 2 Quad Core CPU nodes HP BLc7000 Linux cluster (total 128 CPUs), 16 GB RAM per node 2 HP Proliant DL580G4 servers on Linux, 4 x dual core CPUs, 16 GB RAM per server 3 x dual monitor HP xw6400 work stations 44 TB disk space
Software	Paradigm Focus 5.4 FSI Uniseis 0804 64 bit and 32 bit RedHat Enterprise 4 Linux
Capabilities	Full 3D QC processing, fast track full fold cube at acquisition speed
Tape drives	4 x IBM Magstar 3590E 4 x IBM Jaguar-2 3592
Plotters	HP 1050C A0 plotter OYO GS 36’’ thermal plotter
Data compression software	Aware Seispact v 3.61

BRIEF SPECIFICATION
for
TANUX I

Type	Work / Maintenance
Classification	American Bureau of Shipping +A1(E) +AMS
ABS PID	
Flag State	NIS – Norway
Official Number	
Call Sign	LAGT6
Owner	Tanux Shipping KS
Operator	Tananger Offshore AS
Designer	Conan Wu & Associates Pte Ltd
Builders	Cheoy Lee Shipyards Ltd & Hin Lee (Zhuhai) Shipyard Co Ltd
Yard No.	4881
Construction Material	Steel
Length Overall	53.80 metres
Length BP	51.50 metres
Beam Moulded	13.80 metres
Depth Moulded	4.50 metres
Draft loaded max.	3.60 metres
Displacement Loaded	1800 tonnes approx.
Deadweight	1060 tonnes approx.
Tonnage	1050 approx.
Complement	50 persons
F.O. Tankage	
F.W. Tankage	
S.W. Ballast Tankage	
Maximum Speed	13 knots approx.
Main Engines	2 x Caterpillar 3512B, 1575 bhp at 1800 rpm
Gearboxes	2 x Reintjes WAF663 5.044:1 ratio
Propulsion	2 x fixed pitch propellers in nozzles
Generating Sets	3 x Caterpillar 300 kVA
Emergency Genset	Lister CS-4
Bow Thruster	Schottel STT-110-LK
Bow Thruster Gearbox	ZF 220 1.963:1 ratio
Bow Thruster Engine	Caterpillar 3126B 315 bhp / 2400 rpm

Steering Gear : Jastram SZ-44-2-35
Switchboards : Terasaki
Starting Air Compressors : 2 x Sperre / HL 2/77
External Fi-Fi System : CounterFire 1200m^3/hr
Oily Water Separator : Taiko Kikai USC-10 x LD-INSA
Sewage Treatment Plant : Taiko Kikai SBT-40
Pumps : Desmi, Itur, Azcue
Watermaker : Sea Recovery 1500-2 GPD
Anchor Windlass : Plimsoll PR-HAW/GG-34U2
Engine Telegraph : Engtek TELMAC II-24
Search Lights : Francis L480C
Floodlights : KDECOM 500W
Navigation Lights : Aqua Signal 70M
Signalling Lantern : Francis FSP127
Radars : Furuno FP-2115 & 1942 MK2
MF / HF SSB : Furuno FS-1570
VHF : 2 x Furuno FM-8500
Speed Log : Furuno DS-80
Echo Sounder : Furuno FE-700
Navtex Receiver : Furuno NX-500
Portable GMDSS VHF : 3 x Icom GM-1500
Gyro Compass : Anschuetz Standard 20 Compact
Magnetic Compass : Saura MR-150
Auto-pilot : Auschuetz Pilostar D
GPS : Furuno GP-90
Radar Transponder : 2 x McMurdo S4
EPIRB : McMurdo E3
Sound Powered Telephone : PhonTech BTS-4000
Intercom : PhonTech CIS-3100
Public Address : PhonTech SPA-1500
Mini-M : Nera Worldphone
Anemometer : Navman W-3150
Automatic ID System : Furuno FA-100
Inmarsat-C : Furuno FELCOM-15
SSAS : Furuno FELCOM-16

****

Norseman
Maritime Charters

NORSEMAN
108 ft. Research Vessel

DIMENSIONS AND REGULATORY INFORMATION

Length:	108 ft.	**Beam:**	28 ft.	**Draft:**	13 ft.
Gross Tons:	197	**Deck Levels:**	3		

Documentation:	United States
Sewage Treatment System:	Type II MSD Coast Guard Approved

PERFORMANCE & PROPULSION

Speed:	10 Knots
Endurance:	90+ Days
Range:	10,000 Miles

Propulsion:	850 hp Cat Diesel
Fuel Consumption (@ 8knots)	450 gal. per Day

MACHINERY

Electric Generators:	1- NL 40 kW 1- Cat 90 kW 1- Cat 135 kW
Electrical Power:	110 Volt AC 208 Volt AC 3 Phase 480 Volt AC 3 Phase

CAPACITY

Fuel Capacity	40,000 gal.
Fresh Water Holding:	4,500 gal.
Fresh Water Making:	1,200 gal., per day
Walk in Freezer:	400 cu ft.
Walk in Cooler:	300 cu ft.
Open Deck Area:	1,400 sq ft.

ACCOMMODATIONS

Berths:	5 researcher cabins capable of sleeping 12 (can be configured to accommodate 18 to 20 depending on needs), plus separate quarters for 8 crew
Bathrooms:	7 units each with a toilet, shower, and vanity
Dinning:	Separate guest and crew messes

SPECIAL FEATURES

Hydraulic Boom Crane:	20,000 Lbs. SWL @ 20’ 10,000 lbs.
Stern Mounted A-Frame:	SWL 5,000 lbs.
Hydraulic Deck Winch:	2,000 lbs., line pull 1,000 ft., 3/8 wire
Anchor Winch:	75 Fathoms ground gear
Skiff Launching Ability:	Up to 27’ rigid

ELECTRONICS AND COMMUNICATIONS

Radar: Furuno 1510D, Furuno Navnet VX2 Radar and Plotter; GPS: Furuno GP-32, Northstar 952X; AIS: Furuno FA-150; Depth Sounders: Furuno FCV-292 Color Sounder, Furuno FE 881 II Recording Sounder; **Communications:** Furuno FS400 Single Side Band, Furuno FS4001 Single Side Band, Stephens SEA 222 Single Side Band, Two VHF Radios, Iridium Satellite phone, One Icom, three Portable Handheld VHFs

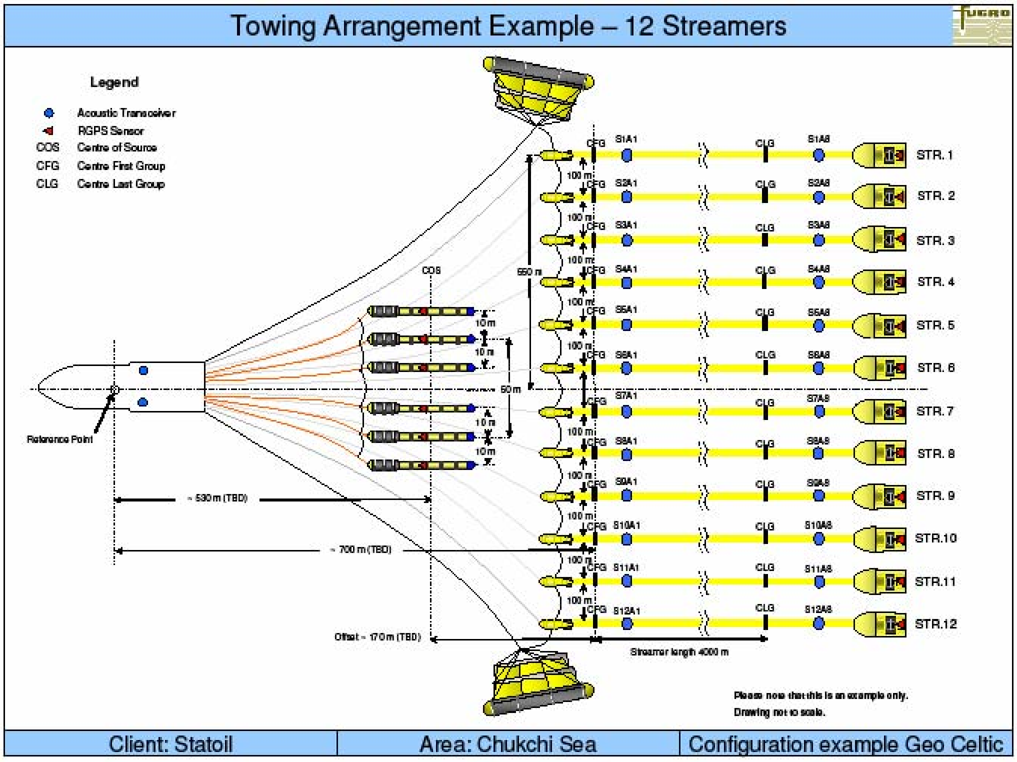
P.O. Box 9322, Seattle, WA 98109 * ph: 206-403-3630
Web: www.norsemanmaritime.com * e-mail: info@norsemanmaritme.com

APPENDIX B:
AIRGUN ARRAY DESCRIPTION

1 TECHNICAL SPECIFICATION

Source	
Source type	Sodera Airguns GC-I-3000-60-D-2000
Number of sources	2
Source separation [m]	50 m
Operation Pressure [psi]	2000
Volume (per source) [cu.in]	3000
No of sub arrays (per source)	3
Sub array separation [m]	10
Source depth [m]	6
Shotpoint interval [m]	18.75
Source shooting sequence	Odd shots = starboard source
Minimum time between shots [ms]	7000
Streamer	
Streamer type	Sercel Sentinel solid
Number of streamers	12
Streamer separation [m]	100
Streamer length (per streamer) [m]	4050
Number of groups (per streamer)	324
Group length [m]	12.5
Streamer depth [m]	8
Streamer steering	DigiFin
Inline offset (centre src/centre near trace) [m]	170
Recording	
Recording system	Sercel Seal, 24 bit digital
CMP-line separation [m]	25
Bin size acquisition (in-line/x-line) [m]	12,5/18.75
Nominal shooting direction [deg]	090/270 (Grid)
Recording length (after T_0) [ms]	5000
Sample rate [ms]	2
Recording filter – Low cut/slope [Hz@dB/oct]	3Hz / 6dB octave
Recording filter - High cut/slope [Hz@dB/oct]	206 Hz /370dB
Tape format	SEG 8058
Tape media	IBM 3592
Scalar factor to convert recorded amplitude (usually in mVolt) to µbar	19.73 V7bar

2 TOWING CONFIGURATION



Towing Arrangement Example – 12 Streamers

Please note that this is an example only.
Drawing not to scale.

Client: Statoil | Area: Chukchi Sea | Configuration example Geo Celtic

3 SOURCE SPECIFICATION

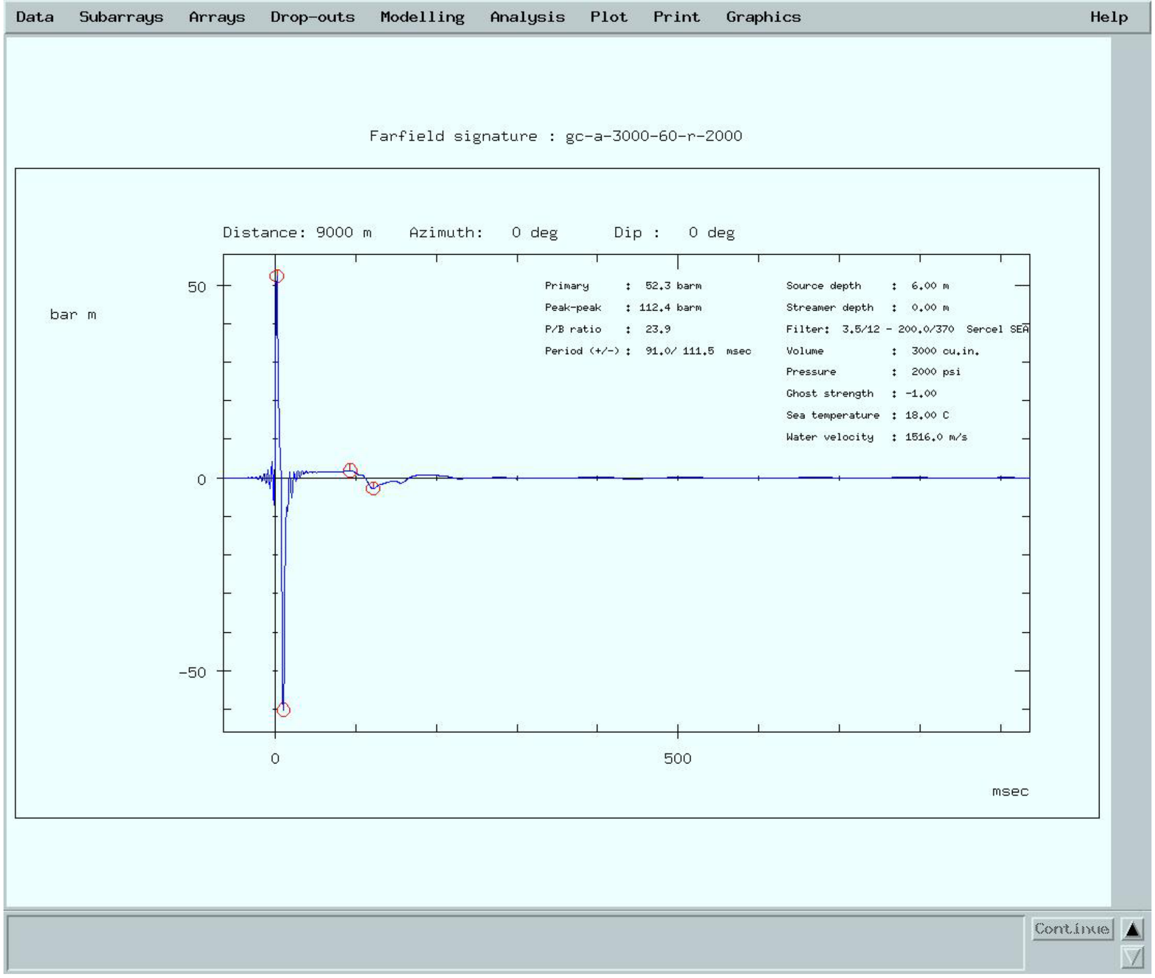
The Seismic source based on an array Sodera G-guns, various chamber volume. The controlled release of air, will give a pulse with following characteristsics

Farfield signature was generated by Nucleus version 6.5.4
Farfield signature was generated by Marine source modelling version 5.2.4

Array name : gc-a-3000-60-r-2000
Total volume : 3000 cu.in.
Source depth : 6.00 m
Streamer depth : 0.00 m
Group length : 12.50 m
Average pressure : 2000 psi
Ghost strength : -1.00
Primary amplitude : 52.26 bar m
Peak-peak amplitude : 112.43 bar m
P/B-ratio : 23.92
Bubble period (+) : 91.00 msec
Bubble period (-) : 111.50 msec
Seawater temperature : 18.00 C
Seawater velocity : 1516.0 m/s

Filter :
Low-cut frequency : 3.50 Hz
Low-cut slope : 12.00 dB/oct
High-cut frequency : 200.00 Hz
High-cut slope : 370.00 dB/oct
Instrument : Sercel SEAL mp
Time of 1st sample : -64.00 msec i.e. index of time zero = 33.00
Sample interval : 2.00 msec
Farfield position :
Distance : 9000.00 m
Azimuth : 0.00 deg
Angle of vertical : 0.00 deg

Signature

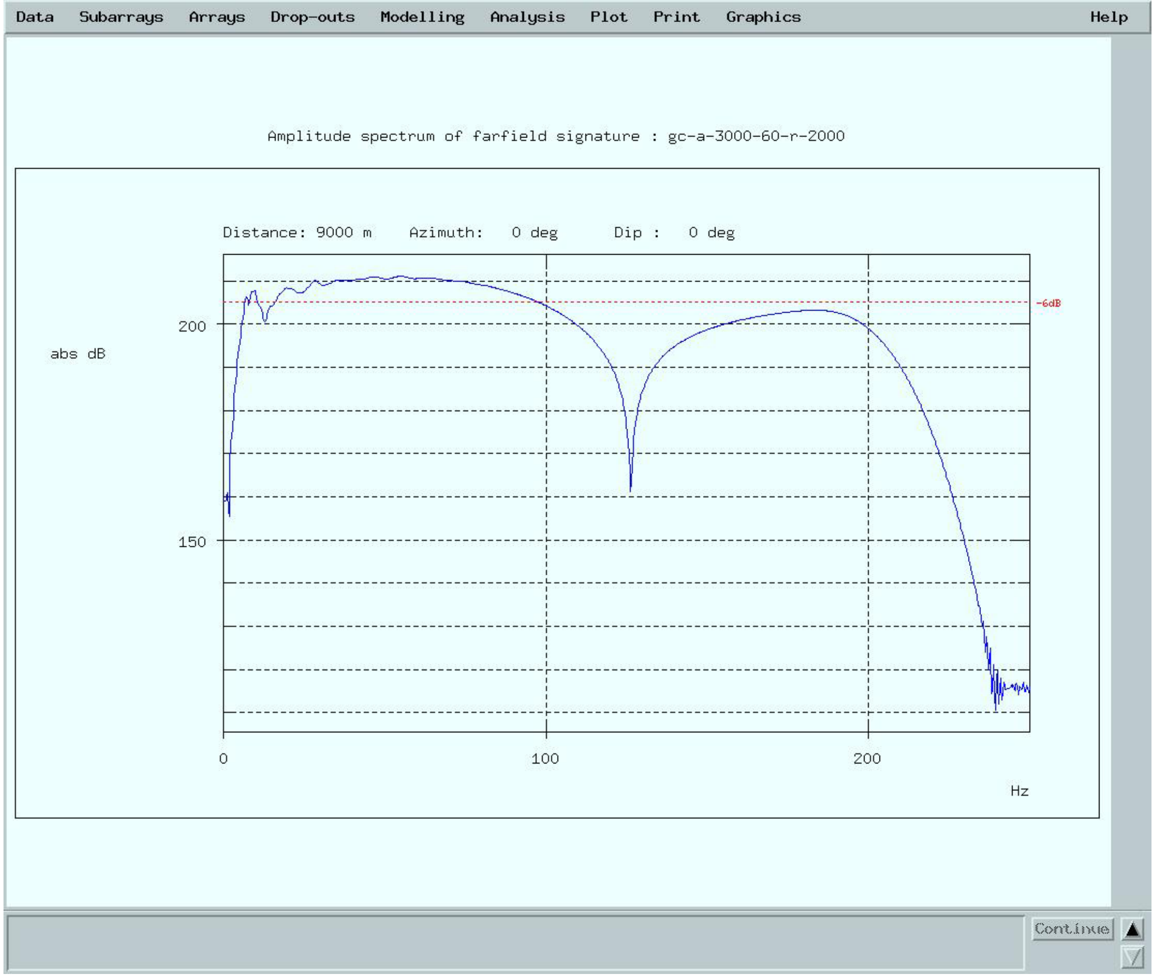


Farfield signature : gc-a-3000-60-r-2000

Distance: 9000 m Azimuth: 0 deg Dip : 0 deg

```
Primary       :  52.3 barm          Source depth     :  6.00 m
Peak-peak     : 112.4 barm          Streamer depth   :  0.00 m
P/B ratio     :  23.9               Filter:  3.5/12 - 200.0/370  Sercel SEA
Period (+/-) :  91.0/ 111.5  msec   Volume           :  3000 cu.in.
                                    Pressure         :  2000 psi
                                    Ghost strength   : -1.00
                                    Sea temperature  : 18.00 C
                                    Water velocity   : 1516.0 m/s
```

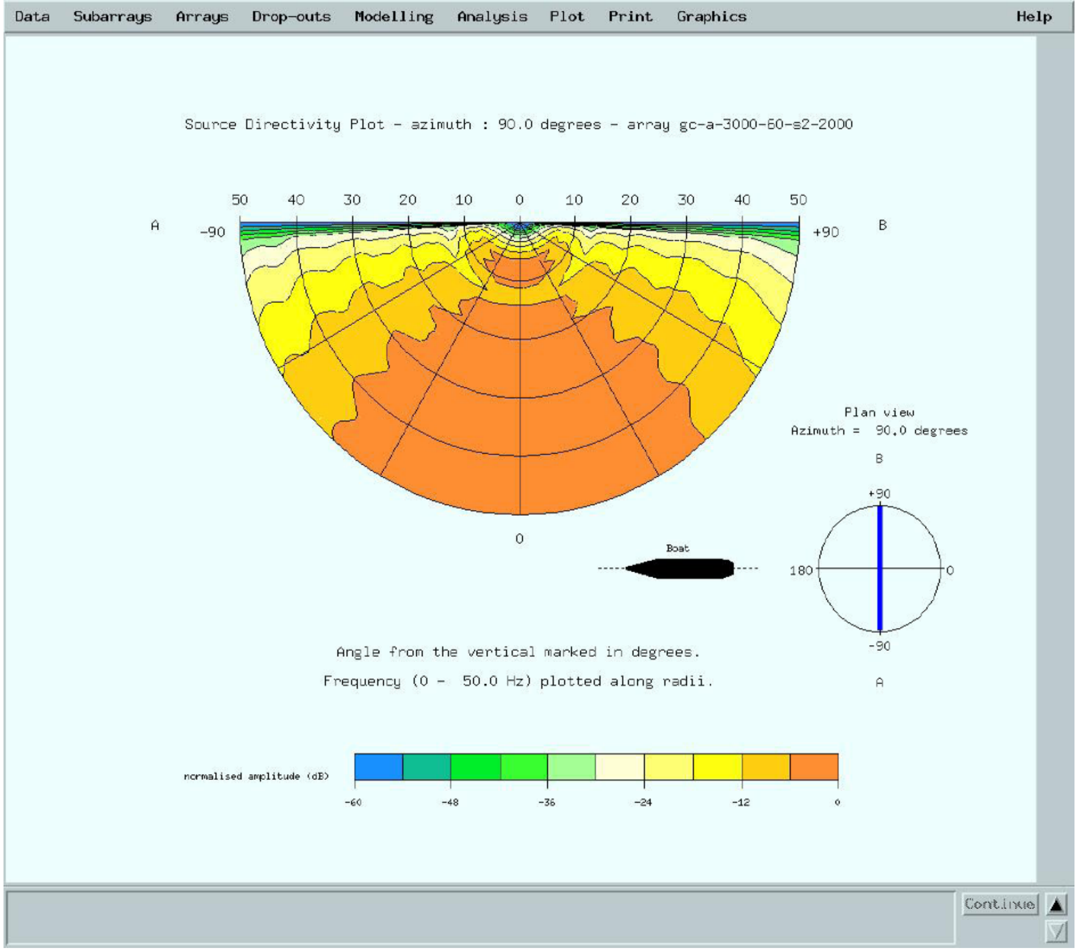
Amplitude



Amplitude spectrum of farfield signature : gc-a-3000-60-r-2000

Distance: 9000 m Azimuth: 0 deg Dip : 0 deg

Directivity



Source Directivity Plot - azimuth : 90.0 degrees - array gc-a-3000-60-s2-2000

Angle from the vertical marked in degrees.

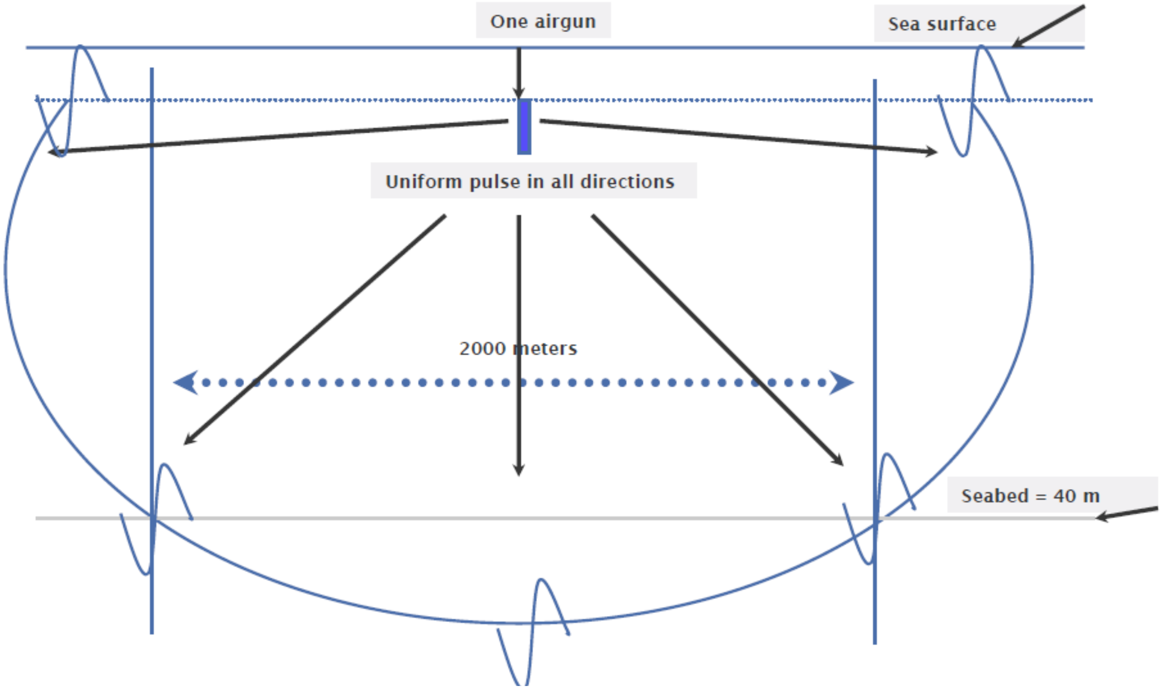
Frequency (0 - 50.0 Hz) plotted along radii.

4 TOWED RECEIVER ARRAY

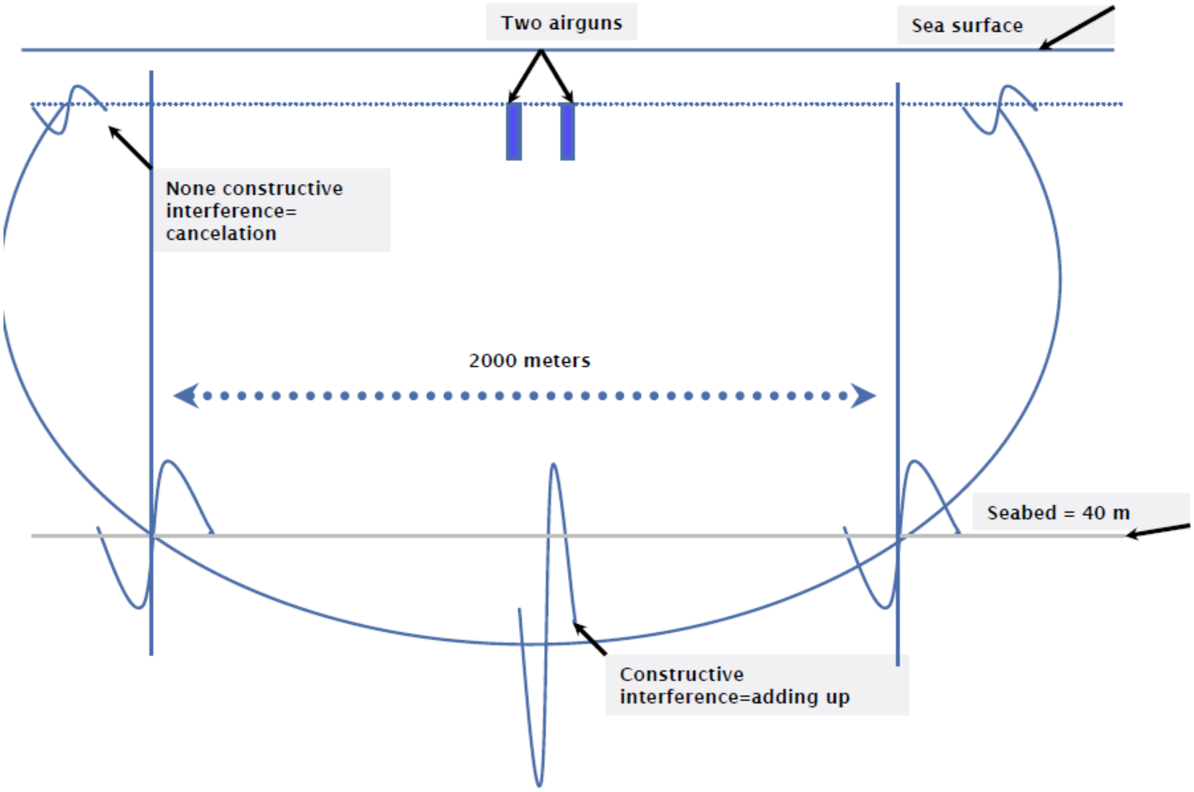
STREAMER

Type	Sercel Sentinel solid streamer
Length	12 x 4050 m
Available group interval	12.5 m
Section length	150 m
Groups pr. Section	12
Hydrophone type	Sercel Flexible Hydrophone NH-96-250
No. of hydrophones/group	8
Streamer diameter	59.5 mm
Streamer sensitivity	19.73 V/bar
Fault locator	Sercel Seal
Compasses	ION Model 5011 Compass Bird
Streamer control	ION Model 5011 Compass Bird ION DigiFIN lateral bird
Acoustics	Sonardyne SIPS2

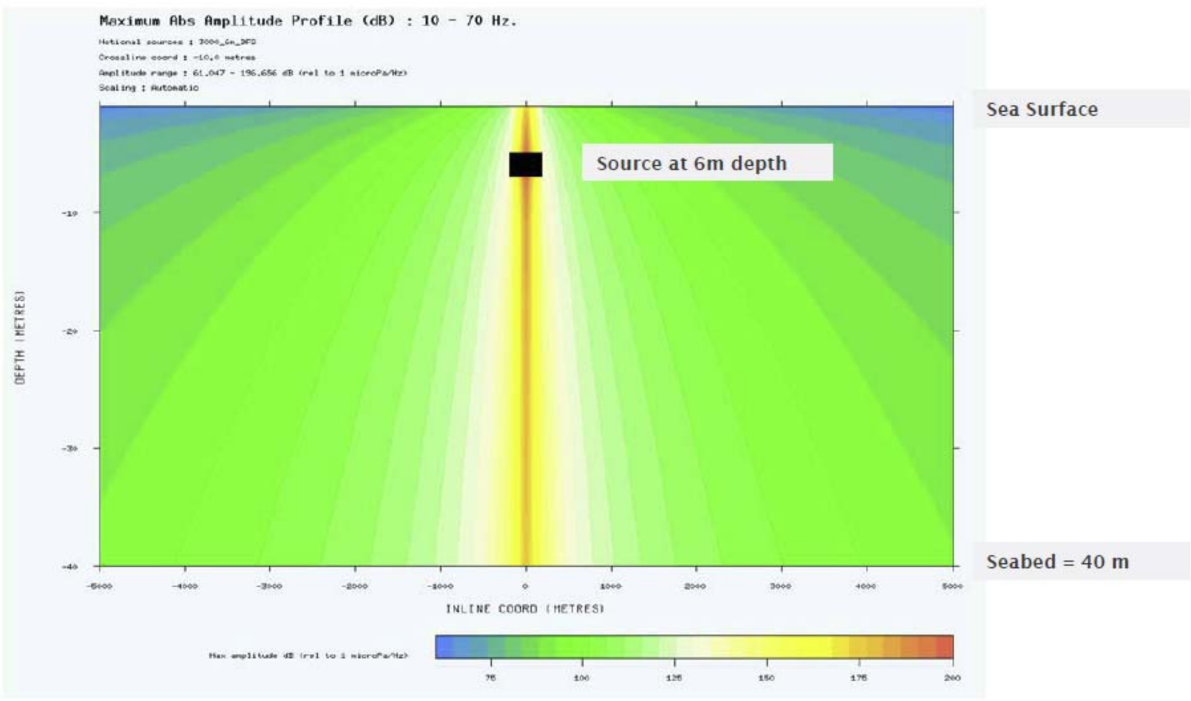
Energy source – Directivity - Single airgun



Energy source – Directivity – Two airguns



Exposure as function of distance from source.



APPENDIX C:
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.[1] Because the level of a given pulse will differ substantially depending on which of these measures is being applied, it is important to be aware which measure is in use when interpreting any quoted pulse level. In the past, the U.S. National Marine Fisheries Service (NMFS) has commonly referred to rms levels when discussing levels of pulsed sounds that might "harass" marine mammals.

Seismic sound pulses received at any given point will arrive via a direct path, indirect paths that include reflection from the sea surface and bottom, and often indirect paths including segments through the bottom sediments. Sounds propagating via indirect paths travel longer distances and often arrive later than sounds arriving via a direct path. (However, sound traveling in the bottom may travel faster than that in the water, and thus may, in some situations, arrive slightly earlier than the direct arrival despite traveling a greater distance.) These variations in travel time have the effect of lengthening the duration of the received pulse, or may cause two or more received pulses from a single emitted pulse. Near the source, the predominant part of a seismic pulse is ~10–20 ms in duration. In comparison, the pulse duration as

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

received at long horizontal distances can be much greater. For example, for one airgun array operating in the Beaufort Sea, pulse duration was ~300 ms at a distance of 8 km, 500 ms at 20 km, and 850 ms at 73 km (Greene and Richardson 1988).

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

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

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

4. MASKING EFFECTS OF AIRGUN SOUNDS

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

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

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

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

A few cetaceans are known to increase the source levels of their calls in the presence of elevated sound levels, shift their peak frequencies in response to strong sound signals, or otherwise modify their vocal behavior in response to increased noise (Dahlheim 1987; Au 1993; reviewed in Richardson et al. 1995:233*ff*, 364*ff*; Lesage et al. 1999; Terhune 1999; Nieukirk et al. 2005; Scheifele et al. 2005; Parks et al. 2007a, 2009; Di Iorio and Clark 2009; Hanser et al. 2009). It is not known how often these types of responses occur upon exposure to airgun sounds. However, blue whales in the St. Lawrence Estuary significantly increased their call rates during sparker operations (Di Iorio and Clark 2009). The sparker, used to obtain seismic reflection data, emitted frequencies of 30–450 Hz with a relatively low source level of 193 dB re 1 $\mu Pa_{pk\text{-}pk}$. 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 $\mu\text{Pa}_{\text{rms}}$ seem to cause obvious avoidance behavior in a substantial portion of the animals exposed (Richardson et al. 1995). In many areas, seismic pulses from large arrays of airguns diminish to those levels at distances ranging from 4–15 km from the source. More recent studies have shown that some species of baleen whales (bowheads and humpbacks in particular) at times show strong avoidance at received levels lower than 160–170 dB re 1 $\mu\text{Pa}_{\text{rms}}$. The largest avoidance radii involved migrating bowhead whales, which avoided an operating seismic vessel by 20–30 km (Miller et al. 1999; Richardson et al. 1999). In the cases of migrating bowhead (and gray) whales, the observed changes in behavior appeared to be of little or no biological consequence to the animals—they simply avoided the sound source by displacing their migration route to varying degrees, but within the natural boundaries of the migration corridors (Malme et al. 1984; Malme and Miles 1985; Richardson et al. 1995). Feeding bowhead whales, in contrast to migrating whales, show much smaller avoidance distances (Miller et al. 2005; Harris et al. 2007), presumably because moving away from a food concentration has greater cost to the whales than does a course deviation during migration.

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

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

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

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

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

Bowhead Whales.—Responsiveness of bowhead whales to seismic surveys can be quite variable depending on their activity (feeding vs. migrating). Bowhead whales on their summer feeding grounds in the Canadian Beaufort Sea showed no obvious reactions to pulses from seismic vessels at distances of 6–99 km and received sound levels of 107–158 dB on an approximate rms basis (Richardson et al. 1986); their general activities were indistinguishable from those of a control group. However, subtle but statistically significant changes in surfacing–respiration–dive cycles were evident upon statistical analysis. Bowheads usually did show strong avoidance responses when seismic vessels approached within a few kilometers (~3–7 km) and when received levels of airgun sounds were 152–178 dB (Richardson et al. 1986, 1995; Ljungblad et al. 1988; Miller et al. 2005). 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 $\mu\text{Pa}_{\text{rms}}$. 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 $\mu\text{Pa}_{\text{peak}}$ 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 $\mu\text{Pa}_{\text{rms}}$. Some slight behavioral changes were noted when approaching gray whales reached the distances where received sound levels were 140 to 160 dB re 1 $\mu\text{Pa}_{\text{rms}}$, 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 $\mu\text{Pa}_{\text{rms}}$ (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 $\mu\text{Pa}_{\text{rms}}$ (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.[2] The authors of the Newfoundland reports concluded that, based on observations from the seismic vessel, some mysticetes exhibited localized avoidance of seismic operations (Moulton et al. 2005, 2006a).

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

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

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[2] 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.

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[3] airgun arrays were shooting. Except for the pilot whale and bottlenose dolphin, CPA distances for all of the small odontocete species tested, including killer whales, were significantly farther from large airgun arrays during periods of shooting compared with periods of no shooting. Pilot whales were less responsive than other small odontocetes in the presence of seismic surveys (Stone and Tasker 2006). For small odontocetes as a group, and most individual species, orientations differed between times when large airgun arrays were operating vs. silent, with significantly fewer animals traveling towards and/or more traveling away from the vessel during shooting (Stone and Tasker 2006). Observers' records suggested that fewer cetaceans were feeding and fewer were interacting with the survey vessel (e.g., bow-riding) during periods with airguns operating, and small odontocetes tended to swim faster during periods of shooting (Stone and Tasker 2006). For most types of small odontocetes sighted by observers on seismic vessels, the median CPA distance was ≥0.5 km larger during airgun operations (Stone and Tasker 2006). Killer whales appeared to be more tolerant of seismic shooting in deeper waters.

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

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

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[4] airgun sources were operating, and effects on orientation were evident for all species and groups tested (Stone and Tasker 2006). Results from four NSF-funded L-DEO seismic surveys using small arrays (up to 3 GI guns and 315 in^3) were inconclusive. During surveys in the Eastern Tropical Pacific (Holst et al. 2005b) and in the Northwest Atlantic (Haley and Koski 2004), detection rates were slightly lower during seismic compared to non-seismic periods. However, mean CPAs were closer during seismic operations during one cruise (Holst et al. 2005b), and greater during the other cruise (Haley and Koski 2004). Interpretation of the data was confounded by the fact that survey effort and/or number of sightings during non-seismic periods during both surveys was small. Results from another two small-array surveys were even more variable (MacLean and Koski 2005; Smultea and Holst 2008).

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

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

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: Figure 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 $\mu\text{Pa}_{\text{rms}}$, 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).[5] 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

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[5] 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).

~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.

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 either SEL ≥198 dB re 1 $\mu Pa^2 \cdot s$ or 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 [ed.] 2002) and acoustically-mediated bubble-growth (Crum et al. 2005) are implausible in the case of exposure to broadband airgun pulses. Nonetheless, evidence that sonar signals can, in special circumstances, lead (at least indirectly) to physical damage and mortality (e.g., Balcomb and Claridge 2001; NOAA and USN 2001; Jepson et al. 2003; Fernández et al. 2004, 2005; Hildebrand 2005; Cox et al. 2006) suggests that caution is warranted when dealing with exposure of marine mammals to any high-intensity "pulsed" sound. One of the hypothesized mechanisms by which naval sonars lead to strandings might, in theory, also apply to seismic surveys: If the strong sounds sometimes cause deep-diving species to alter their surfacing–dive cycles in a way that causes bubble formation in tissue, that hypothesized mechanism might apply to seismic surveys as well as mid-frequency naval sonars. However, there is no specific evidence of this upon exposure to airgun pulses.

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

6.4 Non-Auditory Physiological Effects

Based on evidence from terrestrial mammals and humans, sound is a potential source of stress (Wright and Kuczaj 2007; Wright et al. 2007a,b, 2009). However, almost no information is available on sound-induced stress in marine mammals, or on its potential (alone or in combination with other stressors) to affect the long-term well-being or reproductive success of marine mammals (Fair and Becker

2000; Hildebrand 2005; Wright et al. 2007a,b). Such long-term effects, if they occur, would be mainly associated with chronic noise exposure, which is characteristic of some seismic surveys and exposure situations (McCauley et al. 2000a:62*ff*; Nieukirk et al. 2009) but not of some others.

Available data on potential stress-related impacts of anthropogenic noise on marine mammals are extremely limited, and additional research on this topic is needed. We know of only two specific studies of noise-induced stress in marine mammals. ***(1)*** Romano et al. (2004) examined the effects of single underwater impulse sounds from a seismic water gun (source level up to 228 dB re 1 μPa · $m_{p\text{–}p}$) 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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