Request by Statoil for an Incidental Harassment Authorization to Allow the Incidental Take of Marine Mammals during a Shallow Hazards Survey in the Chukchi Sea, Alaska, 2011

submitted by

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to

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SUMMARY

Statoil plans to conduct shallow hazards site surveys and soil investigations (geotechnical boreholes) in the Chukchi Sea during the open water season of 2011. Statoil's activities in the Chukchi Sea will begin on or about 1 August, 2011 and continue through October. However, if weather permits and all planned activities have not been completed, survey activities may continue as late as 15 November.

Shallow hazards site surveys are designed to collect bathymetric and shallow sub-seafloor data that allow the evaluation of potential shallow faults, gas zones, and archeological features at prospective exploration drilling locations. Performing the site surveys prior to actual operations will identify any areas that may pose a hazard to those operations, such that they can be avoided. Geotechnical soil investigations are performed to collect samples and detailed data of seafloor sediments to a maximum depth of 100 m.

The ***shallow hazards*** and site clearance surveys will use a towed airgun cluster consisting of four, 10-in^3 airguns with a ~600 m towed hydrophone streamer, as well as additional lower-powered and higher frequency survey equipment for collecting bathymetric and shallow sub-bottom data. The proposed survey will take place on and near Statoil's leases in the Chukchi Sea, covering a total area of ~665 km^2 located ~240 km (150 mi) west of Barrow and ~ 165 km (103 mi) northwest of Wainwright, in water depths of ~30–50 m (100–165 ft).

Geotechnical soil investigations will take place at prospective drilling locations on Statoil's leases and leases jointly owned with ConocoPhillips Alaska Inc. (CPAI). All cores will be either 2.1 in. or 2.8 in. in diameter (depending on soil type) and those collected at prospective drilling locations will be up to 100 m in depth. The maximum total number of samples collected as part of the drilling location and site survey program will be ~29.

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 monitoring and mitigation program to minimize the impacts of the proposed activity on marine mammals during the activities 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 activities. A request for a Letter of Authorization (LoA) will be submitted separately to the U.S. Fish & Wildlife Service with regard to potential effects on species managed by USFWS – the Pacific walrus and polar bear.

I. OPERATIONS TO BE CONDUCTED

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

Statoil acquired 16 leases in the Chukchi Sea during Lease Sale 193 held in February 2008. The leased areas are located ~240 km (150 mi) west of Barrow and ~160 km (~100 mi) northwest of Wainwright. During the open-water season of 2010, Statoil conducted a 3D seismic survey over its lease holdings and the surrounding area. The data gathered during that survey are currently being analyzed in order to determine potential well locations on the leases. These analyses will be completed prior to commencement of the site survey program. During the open-water season of 2011, Statoil proposes to conduct shallow hazards and site clearance surveys (site surveys) and soil investigations (geotechnical boreholes).

Shallow Hazards and Site Clearance Surveys

Shallow hazards site surveys are designed to collect bathymetric and shallow sub-seafloor data that allow the evaluation of potential shallow faults, gas zones, and archeological features at prospective exploration drilling locations, as required by the Bureau of Ocean Energy Management, Regulation, and Enforcement (BOEMRE). Data are typically collected using multiple types of acoustic equipment. During the site surveys, Statoil proposes to use the following acoustic sources: 4×10 in^3 airgun cluster, single 10 in^3 airgun, Kongsberg SBP3000 subbottom profiler, GeoAcoustics 160D side-scan sonar, and a Kongsberg EM2040 multibeam echosounder. The operating frequencies and estimated source levels of this equipment are provided below.

Statoil has contracted with Gardline CGGVeritas who will use their vessel M/V *Duke* to perform the site surveys in the Chukchi Sea (see Appendix A for vessel specifications). Site surveys will primarily occur on Statoil leases, with some overlap onto neighboring leases or unleased acreage in order to provide uniform coverage of the area. A coarse grid of data using all acoustics sources (including the 4×10 in^3 airgun cluster) will be collected across the rectangular areas covering Statoil's leases as shown in Fig. 1. More detailed data, again using all acoustics sources, will be collected using closely spaced lines at ~5 potential exploration drilling locations on Statoil's leases. In total, a maximum of 2500 km of survey line are planned to occur on or near Statoil leases covering a total area of ~665 km^2.

Geotechnical Soil Investigations

Geotechnical soil investigations are performed to collect detailed data on seafloor sediments and geological structure to a maximum depth of 100 m. These data are then evaluated to help determine the suitability of the site as a drilling location. Statoil has contracted with Fugro who will use the vessel M/V *Fugro Synergy* (Appendix A) to complete the planned soil investigations. Three to four bore holes will be collected at each of up to 5 prospective drilling locations on Statoil's leases and up to 3 boreholes may be completed at each of up to 3 potential drilling locations on leases jointly owned with CPAI. This results in a maximum total of 29 bore holes to be completed as part of the geotechnical soil investigation program. The *Fugro Synergy* operates a Kongsberg EA600 Echosounder and uses a Kongsberg 500 high precision acoustic positioning (HiPAP) system for precise vessel positioning while completing the boreholes. The operating frequencies and estimated source levels of the acoustic equipment, as well as the sounds produced during soil investigation sampling, are provided in the sub-section below.

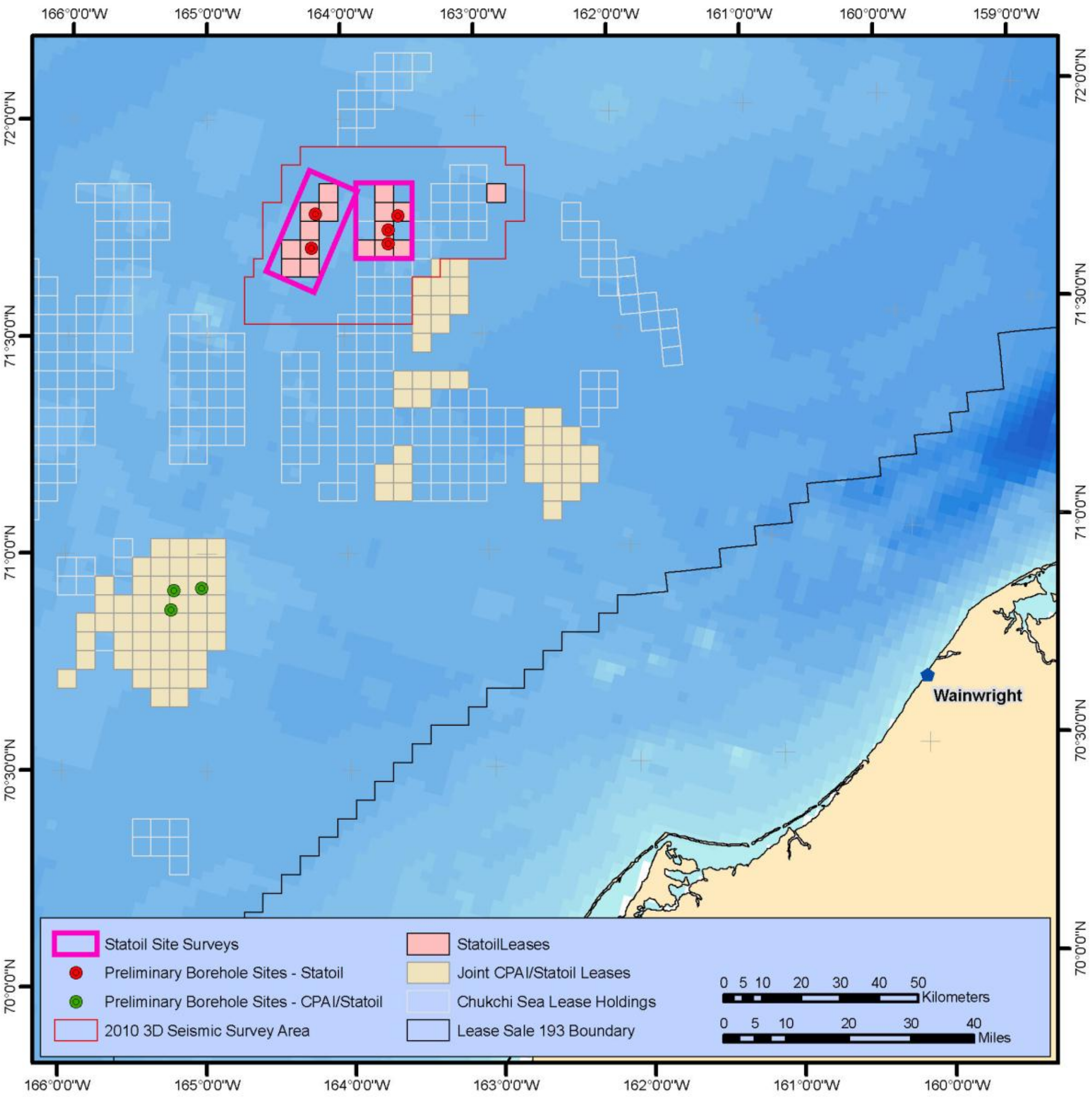

Figure 1. Location of the planned 2011 site survey and geotechnical soil investigation activities in the Chukchi Sea, Alaska.

Acoustic Sources

Airguns

A 4×10 in^3 airgun cluster will be used to obtain geological data during the shallow hazards survey. A similar airgun cluster was measured by Shell in 2009 during shallow hazards surveys on their nearby Burger prospect (Reiser et al. 2010). The measurements resulted in 90th percentile propagation loss equations of RL = 218.0 - 17.5LogR - 0.00061R for a 4×10 in^3 airgun cluster and RL = 204.4 - 16.0LogR - 0.00082R for a single 10 in^3 airgun (where RL = received level and R = range). For use in estimating potential harassment takes in this application, as well as for mitigation radii to be implemented by MMOs prior to SSV measurements (see §XI and §XIII), ranges to threshold levels from the 2009 measurements were increased by 25% as a precautionary approach (Table 1).

Table 1. Distances to specified received levels measured from a 4×10 in^3 airgun cluster and a single 10-in^3 airgun on the Burger prospect in 2009 as reported by Reiser et al. (2010) and 2011 "Pre-SSV" distances used for estimation purposes in this application based on a precautionary 25% increase above the reported 2009 results.

	Distance (m)			
Received Level	Airgun Cluster (4×10 in^3)		Mitigation Airgun (1×10 in^3)	
dB re 1µPa rms	2009 Results	2011 pre-SSV	2009 Results	2011 pre-SSV
≥190	39	50	8	10
≥180	150	190	34	45
≥160	1,800	2,250	570	715
≥120	31,000	39,000	19,000	24,000

Kongsberg SBP300 Sub-bottom Profiler

This instrument will be operated from the M/V *Duke* during site survey operations. This sub-bottom profiler operates at frequencies between 2 and 7 kHz with a source level of ~225 dB re 1 µPa · m. The sound energy is projected downwards from the hull in a maximum 15° cone.

Field measurements of similar instruments in previous years have resulted in much lower actual source levels (range 161-186 dB) than specified by the manufacturers (i.e. the manufacturer source level of one instrument was reported as 214 dB, and field measurements resulted in a source level estimate of 186.2 dB) (Chorney et al. 2011; Patterson et al. 2007). However, it is not known whether these field measurements captured the narrow primary beam produced by the instruments. Statoil will measure the sounds produced by this instrument (and all other survey equipment) at the start of operations. If sounds from the instrument are found to be above mitigation threshold levels (180 dB for cetaceans and walrus, 190 dB for seals and polar bears) at distance beyond the footprint of the vessel, then the same power-down and shut-down mitigation measures used during airgun operations will be employed during use of the sub-bottom profiler.

GeoAcoustics 160D Sidescan Sonar

The sidescan sonar will be operated from the M/V *Duke* during site survey operations. This unit operates at 114 kHz and 410 kHz with a source level of ~233 dB re 1 µPa · m. The sound energy is emitted in a fan shaped patter that is narrow (0.3–1.0°) in the fore/aft direction of the vessel and broad (40–50°) in the port/starboard direction.

Kongsberg EM2040 Multibeam Echosounder

Multibeam echosounders also emit energy in a fan-shaped pattern, similar to the sidescan sonar described above. This unit operates at 200 to 400 kHz with a source level of ~210 dB re 1 µPa · m. The beam width is 1.5° in the fore/aft direction. The multibeam echosounder will be operated from the M/V *Duke* during site surveys operations.

Kongsberg EA600 Echosounder

This echosounder will be operated from the M/V *Fugro Synergy* routinely as a fathometer to provide depth information to the bridge crew. This model is capable of simultaneously using 4 transducers, each with a separate frequency. However, only 2 transducers will be mounted and used during this project. These transducers will operate at 18 kHz and 200 kHz and have similar or slightly lower source levels than the multibeam echosounder described above. The energy from these transducers is emitted in a conical beam from the hull of the vessel downward to the seafloor.

Kongsberg HiPAP 500

The Kongsberg high precision acoustic positioning system (HiPAP) 500 is used to aid the positioning of the M/V *Fugro Synergy* during soil investigation operations. An acoustic signal is sent and received by a transponder on the hull of the vessel and a transponder lowered to the seafloor near the borehole location. The two transponders communicated via signals with a frequency of between 21–30.5 kHz with source levels expected to be in the 200–210 dB range.

Geotechnical Soil Investigation Sounds

In-water sounds produced during soil investigation operations by the M/V *Fugro Synergy* have not previously been measured and estimates of such activities vary. Measurements of another Fugro vessel that often conducts soil investigations were made in the Gulf of Mexico in 2009. However, because measurements were taken using a towed hydrophone system, recordings of soil investigation related sounds could not be made while the vessel was stationary. Therefore, sounds recorded while the vessel was in transit were compared to sounds recorded while the vessel also operated generators and mechanical equipment associated with soil investigation operations while in transit. The difference in sound levels during transit alone and during transit with soil investigation equipment operating was negligible and this was attributed to the fact that transit noise was dominant up to at least 7 kHz and likely masked the lower frequency sounds produced by the simulated soil investigation activities.

During soil investigation operations, the *Fugro Synergy* will remain stationary relative to the seafloor by means of a dynamic positioning (DP) system that automatically controls and coordinates vessel movements using bow and/or stern thrusters as well as the primary propeller(s). The sounds produced by soil investigation equipment are not likely to substantially increase overall source levels beyond those produced by the various thrusters while in DP mode. Measurements of a vessel in DP mode with an active bow thruster were made in the Chukchi Sea in 2010 (Chorney et al. 2011). The resulting source level estimate was 175.9 dB re 1 μPa · m (rms). Using the transmission loss equation from measurements of a single 60 in^3 airgun on Statoil's lease in 2010 (RL = 205.6 – 13.9LogR – 0.00093R; O'Neill et al. 2011) and replacing the constant term with the 175.9 results in an estimated range of 4.97 km to the 120 dB level. To allow for uncertainties and some additional sound energy being contributed by the operating soil investigation equipment, an inflation factor of 1.5 was applied to arrive at an estimated ≥120 dB radius of 7.5 km for soil investigation activities.

II. DATES, DURATION, AND REGION OF ACTIVITY

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

As noted in the previous section, the planned operations will be performed from two different vessels. Site surveys will be conducted from the M/V *Duke*, while geotechnical soil investigations will be conducted from the M/V *Fugro Synergy* (see Appendix A for vessel specifications). Both vessels will mobilize from Dutch Harbor in late July and arrive in the Chukchi Sea to begin work ~1 August. Allowing for poor weather days, operations are expected to continue into late September or early October. However, if weather permits and all planned activities have not been completed, operations may continue as late as 15 November.

The site survey work on Statoil's leases will require approximately ~23 days to complete. Geotechnical soil investigations on Statoil leases and on leases jointly held with CPAI will require ~14 days of operations.

III. SPECIES AND NUMBERS OF MARINE MAMMALS IN AREA

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

Marine mammals that occur in the area of the planned 2011 site clearance and shallow hazards surveys and geotechnical soil investigations belong to three taxonomic groups: odontocetes (toothed cetaceans, such as beluga whale and narwhal), mysticetes (baleen whales), and carnivora (pinnipeds and polar bears). Cetaceans and pinnipeds (except Pacific walrus) are the subject of this IHA application to NMFS. The Pacific walrus and polar bear are managed by the U.S. Fish & Wildlife Service (USFWS).

Marine mammal species under the jurisdiction of NMFS that are known to or may occur in the area of the planned activities include nine cetacean species and four species of pinnipeds. Three of these species, the bowhead, humpback, and fin whales, are listed as endangered under the U.S. Endangered Species Act (ESA). The bowhead whale is more common in the area than the other two species. The fin whale is unlikely to be encountered near the survey activities, but a few sightings in the Chukchi Sea have been reported in recent years (COMIDA 2009). Similarly, humpback whales are not known to regularly occur in the Chukchi and Beaufort seas; however, several humpback sightings were recorded during vessel-based surveys in the Chukchi Sea in 2007 (Reiser et al. 2009a).

To avoid redundancy, we have included the required information about the species that are known to or may be present and (insofar as it is known) numbers of these species in § 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 3 and 4 are integrated here to minimize repetition.

Nine cetacean and four seal species could occur in the general area of the site clearance and shallow hazards survey (Table 2). The marine mammal species under NMFS's jurisdiction most likely to occur near operations in the Chukchi and Beaufort seas include four cetacean species (beluga, bowhead and gray whale, and harbor porpoise), and three seal species (ringed, bearded, and spotted seals). The marine mammal species that is likely to be encountered most widely (in space and time) throughout the period of the planned site clearance and shallow hazards surveys is the ringed seal.

Other cetacean species that have been observed in the Chukchi Sea but are uncommon or unlikely to occur near project activities include narwhal, killer whale, minke whale, humpback whale, and fin whale. These species could occur in the vicinity of the planned activities, but each of these species is uncommon or rare in the area and relatively few encounters with these species are expected. The narwhal occurs in Canadian waters and occasionally in the Beaufort Sea, but it is rare there and is not expected to be encountered in the Chukchi Sea.

Table 2. The habitat, abundance, and conservation status of marine mammals inhabiting the area of the planned activities in the Chukchi Sea.

Species	**Habitat**	**Abundance**	**ESA**[1]	**IUCN**[2]	**CITES**[3]
Odontocetes Beluga whale (*Delphinapterus leucas*) (Eastern Chukchi Stock)	Offshore, Coastal, Ice edges	3,710[4]	Not listed	NT	–
Beluga whale (Beaufort Sea Stock)	Offshore, Coastal, Ice edges	39,257[5]	Not Listed	NT	–
Narwhal (*Monodon monoceros*)	Offshore, Ice edge	Rare[6]	Not listed	NT	–
Killer whale (*Orcinus orca*)	Widely distributed	Uncommon	Not listed	DD	–
Harbor Porpoise (*Phocoena phocoena*) (Bering Sea Stock)	Coastal, inland waters, shallow offshore waters	48,215[4] Common[7]	Not listed	LC	–
Mysticetes Bowhead whale (*Balaena mysticetus*)	Pack ice & coastal	10,545[8] 12,631[9]	Endangered	LC	I
Gray whale (*Eschrichtius robustus*) (eastern Pacific population)	Coastal, lagoons, shallow offshore waters	488[10] 17,500[11]	Not listed	LC	I
Fin whale (*Balaenoptera physalus*)	Slope, mostly pelagic	Rare (Chukchi)	Endangered	EN	I
Minke whale (*Balaenoptera acutorostrata*)	Shelf, coastal	Rare	Not listed	LC	I
Humpback whale (*Megaptera novaeangliae*)	Shelf, coastal	Rare	Endangered	LC	I
Pinnipeds Bearded seal (*Erignathus barbatus*)	Pack ice, shallow offshore waters	250,000-300,000[12] 155,000[13]	Proposed Threatened	LC	–
Spotted seal (*Phoca largha*)	Pack ice, coastal haulouts	~59,214[14]	Arctic pop. Segments not listed	LC	–
Ringed seal (*Pusa hispida*)	Landfast & pack ice, offshore	~208,000-252,000[15]	Proposed Threatened	LC	–
Ribbon seal (*Histriophoca fasciata*)	Offshore, pack ice	90-100,000[16]	Not Listed	LC	–

[1] U.S. Endangered Species Act.

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

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

[4] Allen and Angliss (2010)

[5] Beaufort Sea population (IWC 2000, Allen and Angliss 2010).

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

[7] Vessel-based observations from Industry activities in 2006–2007 (Reiser et al. 2009a)

[8] 2001 B-C-B Bowhead population estimate (Zeh and Punt 2005)

[9] 2004 B-C-B Bowhead population estimate (Koski et al. 2010).

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

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

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

[13] Beringia Distinct Population Segment (NMFS 2010a).
[14] Alaska stock based on aerial surveys in 1992 (Allen and Angliss 2010).
[15] Eastern Chukchi Sea population (Bengtson et al. 2005)
[16] Burns, J.J. 1981a.

Odontocetes

Beluga (Delphinapterus leucas)

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

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

In Alaska, beluga whales comprise five distinct stocks: Beaufort Sea, eastern Chukchi Sea, eastern Bering Sea, Bristol Bay, and Cook Inlet (O'Corry-Crowe et al. 1997). For the planned site clearance and shallow hazards surveys, only the Beaufort Sea stock and eastern Chukchi Sea stock may be encountered.

The most recent estimate of the ***eastern Chukchi Sea*** population is 3710 animals (Allen and Angliss 2010). This estimate was based on surveys conducted in 1989–1991. Survey effort was concentrated on the 170-km long Kasegaluk Lagoon where belugas are known to occur during the open-water season. The actual number of beluga whales recorded during the surveys was much lower. Correction factors to account for animals that were underwater and for the proportion of newborns and yearlings that were not observed due to their small size and dark coloration were used to calculate the estimate. The calculation was considered to be a minimum population estimate for the eastern Chukchi Sea stock because the surveys on which it was based did not include offshore areas where belugas are also likely to occur. This population is considered to be stable. It is assumed that beluga whales from the eastern Chukchi stock winter in the Bering Sea (Allen and Angliss 2010).

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

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

Beluga whales from the eastern Chukchi Sea stock are an important subsistence resource for residents of the village of Point Lay, adjacent to Kasegaluk Lagoon, and other villages in northwest Alaska. Each year, hunters from Point Lay drive belugas into the lagoon to a traditional hunting location. The belugas have been predictably sighted near the lagoon from late-June through mid- to late-July (Suydam et al. 2001). In 2007, approximately 70 belugas were also harvested at Kivalina located southeast of Point Hope.

The ***Beaufort Sea population*** was estimated to contain 39,258 individuals as of 1992 (DeMaster 1995; Allen and Angliss 2010). This estimate was based on the application of a sightability correction factor of 2× to the 1992 uncorrected census of 19,629 individuals made by Harwood et al. (1996). This estimate was obtained from a partial survey of the known range of the Beaufort Sea population and may be an underestimate of the true population size. This population is not considered by NMFS to be a strategic stock and is believed to be stable or increasing (Allen and Angliss 2010).

Beluga whales of the Beaufort stock winter in the Bering Sea, summer in the eastern Beaufort Sea, and migrate through offshore waters of western and northern Alaska (Allen and Angliss 2010). 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. 1977; Ljungblad et al. 1984; Richardson et al. 1995b).

Much of the Beaufort Sea seasonal population enters the Mackenzie River estuary for a short period during July–August to molt their epidermis, but they spend most of the summer in offshore waters of the eastern Beaufort Sea, Amundsen Gulf and more northerly areas (Davis and Evans 1982; Harwood et al. 1996; Richard et al. 2001). Belugas are rarely seen in the central Alaskan Beaufort Sea during the early summer, but a number were reported there during early July from aerial surveys in 2008 (Christie et al. 2010). During late summer and autumn, most belugas migrate westward far offshore near the pack ice (Frost et al. 1988; Hazard 1988; Clarke et al. 1993; Miller et al. 1999). During fall aerial surveys in the Alaskan Beaufort Sea, Lyons et al. (2009) reported the highest beluga sighting rates during the first two weeks of September and in the northern part of their survey area.

Moore (2000) and Moore et al. (2000b) suggested that beluga whales select deeper water at or beyond the shelf break independent of ice cover. However, during the westward migration in late summer and autumn, small numbers of belugas are sometimes seen near the north coast of Alaska (e.g., Johnson 1979). Christie et al. (2010) reported higher beluga sighting rates at locations >60 km offshore than at locations nearer shore during aerial surveys in the Alaskan Beaufort Sea in 2006–2008. The main fall migration corridor of beluga whales is ~100+ km north of the coast. Satellite-linked telemetry data show that some belugas of this population migrate west considerably farther offshore, as far north as 76º to 78ºN latitude (Richard et al. 1997, 2001).

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, but the IUCN-World Conservation Union lists the species as ”near threatened” (IUCN 2010). Innes et al. (2002) estimated a population size of 45,358 narwhals in the Canadian Arctic, although only part of the area was surveyed. There are scattered records of narwhal in Alaskan waters, including reports by subsistence hunters, where the species is considered extralimital (Reeves et al. 2002). Thus, it is possible, but very unlikely, that individuals could be encountered in the area of the planned activities.

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 found in deep water (Dahlheim and Heyning 1999). The greatest abundance is thought to be within 800 km (479 mi) of major continents (Mitchell 1975) and the highest densities occur in areas with abundant prey. Both resident and transient stocks have been described. These are believed to differ in several aspects of morphology, ecology, and behavior including dorsal fin shape, saddle patch shape, pod size, home range size, diet, travel routes, dive duration, and social integrity of pods (Allen and Angliss 2010).

Killer whales are known to inhabit almost all coastal waters of Alaska, extending from southeast Alaska through the Aleutian Islands to the Bering and Chukchi seas (Allen and Angliss 2010). 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 or fall. George et al. (1994) reported that 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. Marine mammal observers (MMOs) onboard industry vessels in the Chukchi Sea recorded five killer whale sighting in 2006–2008 (Haley et al. 2010). Although possible, the likelihood of encountering killer whales in the Beaufort Sea near the planned activities is quite low.

Harbor Porpoise (Phocoena phocoena)

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

The subspecies *P. p. vomerina* ranges from the Chukchi Sea, Pribilof Islands, Unimak Island, and the southeastern shore of Bristol Bay south to San Luis Obispo, California. 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. Harbor porpoises present in the Chukchi Sea belong to the Bering Sea group, which includes animals from Unimak Pass northward. Based on aerial surveys in 1999, the Bering Sea population was estimated at 48,215 animals, although this estimate is likely conservative as the surveyed area did not include known harbor porpoise range near the Pribilof Islands or waters north of Cape Newenham (~55°N latitude; Allen and Angliss 2010). Suydam and George (1992) suggested that harbor porpoises occasionally occur in the Chukchi Sea and reported nine records of harbor porpoise in the Barrow area in 1985–1991. More recent vessel-based surveys in the Chukchi Sea found that the harbor porpoise were commonly encountered during summer and fall from 2006–2008 (Haley et al. 2010).

Mysticetes

Bowhead Whale (Balaena mysticetus)

Bowhead whales only occur at high latitudes in the northern hemisphere and have a disjunct circumpolar distribution (Reeves 1980). The bowhead is one of only three whale species that spend their entire lives in the Arctic. Bowhead whales are found in four areas: the western Arctic (Bering, Chukchi, and Beaufort seas) of northeastern Russia, Alaska and northwestern Canada; the Canadian High Arctic and West Greenland (Nunavut, Baffin Bay, Davis Strait, and Hudson Bay); the Okhotsk Sea (eastern Russia); and the Northeast Atlantic from Spitzbergen westward to eastern Greenland. Those four stocks are recognized for management purposes. The largest population is the Western Arctic or Bering–Chukchi–Beaufort (BCB) stock, which includes whales that winter in the Bering Sea and migrate through the Bering Strait, Chukchi Sea and Alaskan Beaufort Sea to the Canadian Beaufort Sea, where they feed during the summer. These whales migrate west through the Alaskan Beaufort Sea in the fall as they return to wintering areas in the Bering Sea. Visual and satellite tracking data show that many bowhead whales continue migrating west past Barrow and through the northern Chukchi Sea to Russian waters before turning southeast toward the Bering Sea (Moore et al. 1995; Mate et al. 2000; Quakenbush 2010). Some bowheads reach ~75ºN latitude during the westward fall migration (Quakenbush et al. 20010.

The pre-exploitation population of bowhead whales in the Bering, Chukchi, and Beaufort seas is estimated to have been 10,400-23,000 whales. Commercial whaling activities may have reduced this population to perhaps 3000 animals (Woodby and Botkin 1993). Up to the early 1990s, the population size was believed to be increasing at a rate of about 3.2% per year (Zeh et al. 1996) despite annual subsistence harvests of 14–74 bowheads from 1973 to 1997 (Suydam et al. 1995). A census in 2001 yielded an estimated annual population growth rate of 3.4% (95% CI 1.7–5%) from 1978 to 2001 and a population size (in 2001) of ~10,470 animals (George et al. 2004, revised to 10,545 by Zeh and Punt [2005]). A population estimate from photo identification data collected in 2004 was 12,631 (Koski et al. 2010) which further supports the estimated 3.4 percent population growth rate. Assuming a continuing annual population growth of 3.4%, the 2011 bowhead population may number around 14,731 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 marine mammal protection act (MMPA) (Allen and Angliss 2010).

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

Some bowheads arrive in coastal areas of the eastern Canadian Beaufort Sea and Amundsen Gulf in late May and June, but most may remain among the offshore pack ice of the Beaufort Sea until mid-summer. After feeding primarily in the Canadian Beaufort Sea and Amundsen Gulf, bowheads migrate westward from late August through mid- or late October. Fall migration into the Alaskan Beaufort Sea is primarily during September and October. However, in recent years a small number of bowheads have been seen or heard offshore from the Prudhoe Bay region during the last week of August (Treacy 1993; LGL and Greeneridge 1996; Greene 1997; Greene et al. 1999; Blackwell et al. 2004, 2009a; Greene et al. 2007). Satellite tracking of bowheads has also shown that some whales move to the Chukchi Sea prior to September (Quakenbush 2010).

The MMS (now BOEMRE) 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 15 to 200 m deep (Miller et al. 2002). Some individuals enter shallower water, particularly in light ice years, but very few whales are ever seen shoreward of the barrier islands in the Alaskan Beaufort Sea. Survey coverage far offshore in deep water is usually limited, and offshore movements may have been underestimated. However, the main migration corridor is over the continental shelf.

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

Westbound bowheads typically reach the Barrow area in mid-September, and are in that area until late October (e.g., Brower 1996). However, over the years, local residents report having seen a small number of bowhead whales feeding off Barrow or in the pack ice off Barrow during the summer. Recently, autumn bowhead whaling near Barrow has normally begun in mid-September to early October, but in earlier years it began as early as August if whales were observed and ice conditions were favorable (USDI/BLM 2005). The recent decision to delay harvesting whales until mid-to-late September has been made to prevent spoilage, which might occur if whales were harvested earlier in the season when the temperatures tend to be warmer. Whaling near Barrow can continue into October, depending on the quota and conditions.

Spring-migrating bowhead whales will pass through the Chukchi Sea prior to the start of survey operations. However, a few whales that may remain in the Barrow area or other parts of the Alaskan Chukchi Sea during the summer months could be encountered during project activities or by transiting vessels. Most encounters with bowhead whales are likely to occur during the westward fall migration through the Chukchi Sea beginning in late September and running through October. The migration through the Chukchi Sea is more diffuse than in the Beaufort Sea, but nonetheless bowheads are likely to be present near some survey activities.

An ongoing GPS tagging study headed by the Alaska Department of Fish and Game (Quakenbush et al. 2010) has provided new and more detailed information on fall bowhead movements across the Chukchi Sea. 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. 2010). Some of these whales have traveled well north of the planned operations, but many have passed near to, or through, the proposed project area. In addition to other planned mitigation, Statoil will operate in consultation with stakeholders to avoid disturbance to subsistence bowhead whaling activities in the Chukchi Sea, should such a subsistence bowhead hunt occur during the period of Statoil's planned activities.

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 planned activities. The larger eastern Pacific or California gray whale population recovered significantly from commercial whaling during its protection under the MMPA (and ESA until 1994) and numbered about 29,758 ±3122 in 1997 (Rugh et al. 2005). However, abundance estimates since 1997 indicate a consistent decline followed by stabilization or gradual recovery. Rugh et al. (2005) estimated the population to be 18,178 ±1780 in winter 2001-2 and Rugh et al. (2008) estimated the population in winter 2006-7 to have been 20,110 ±1766. The eastern Pacific stock is not considered by NMFS to be endangered or to be a strategic stock.

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

Most summering gray whales have historically congregated in the northern Bering Sea, particularly off St. Lawrence Island in the Chirikov Basin (Moore et al. 2000a), and in the southern Chukchi Sea. More recently, Moore et al. (2003) suggested that gray whale use of Chirikov Basin has decreased, likely as a result of the combined effects of changing currents resulting in altered secondary productivity dominated by lower quality food. Coyle et al (2007) noted that ampeliscid amphipod production in the Chirikov Basin had declined by 50% from the 1980s to 2002-3 and that as little as 3-6% of the current gray whale population could consume 10-20% of the ampeliscid amphipod annual production. These data support 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 southwest of Point Barrow at Hanna Shoal and northwest of Point Hope. The distribution of grays was different during aerial surveys in the Chukchi Sea in 2006 and 2007 (Thomas et al. 2010). In 2006, gray whales were most abundant along the coast south of Wainwright and offshore of Wainwright (Thomas et al. 2007), and in 2007, gray whales were most abundant in nearshore areas from Wainwright to Barrow (Thomas et al. 2010). 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.

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. Gray whales are likely to be in the vicinity of the planned activities in the Chukchi Sea and are likely to be one of the most commonly encountered cetacean species.

Minke Whale (Balaenoptera acutorostrata)

Minke whales have a cosmopolitan distribution at ice-free latitudes (Stewart and Leatherwood 1985), and also occur in some marginal ice areas. Allen and Angliss (2010) recognize two minke whale stocks in U.S. waters including (1) the Alaska stock, and (2) the California/Oregon/Washington stock. There is no abundance estimate for the Alaska stock. Provisional estimates of Minke whale abundance based on surveys in 1999 and 2000 are 810 and 1003 whales in the central-eastern and southeastern 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 may be encountered during the activities in the Chukchi Sea where Haley et al. (2010) reported 14 minke whale sightings from 2006–2008 during vessel-based surveys.

Fin Whale (Balaenoptera physalus)

Fin whales are widely distributed in all the world's oceans (Gambell 1985), but typically occur in temperate and polar regions. Fin whales feed in northern latitudes during the summer where their prey include plankton, as well as shoaling pelagic fish, such as capelin Mallotus villosus (Jonsgård 1966a,b).

The North Pacific population's summering grounds span from the Chukchi Sea to California (Gambell 1985). Three fin whale sightings were made in 2008 from industry vessels and NMFS/National Marine Mammal Laboratory (NMML) survey aircraft in the northern Chukchi Sea off of Ledyard Bay indicating that the range of fin whales may be expanding. Population estimates for the entire North Pacific region range from 14,620 to 18,630, however, reliable estimates are not available (Allen and Angliss 2010). Provisional estimates of fin whale abundance in the central-eastern and southeastern Bering Sea are 3,368 and 683, respectively. No estimates for fin whale abundance during the summer in the Chukchi Sea are available. Reiser et al. (2009a) reported a fin whale sighting during vessel-based surveys in the Chukchi Sea in 2006. Fin whale is listed as "endangered" under the ESA and by the International Union for the Conservation of Nature (IUCN), is classified as a strategic stock by NMFS, and it is a CITES Appendix I species (Table 3-1). Fin whales could be encountered in very low numbers during the exploration drilling activities in the Chukchi Sea.

Humpback Whale (Megapter novaeangliae)

Humpback whales are distributed in major oceans worldwide but have apparently been absent from Arctic waters of the North Pacific (Allen and Angliss 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 and filtered when large amounts of water are taken into the mouth and forced out through the baleen plates. Humpbacks have large, robust bodies and long pectoral flippers which may reach 1/3 of their body length. They are frequently observed breaching or engaged in other surface activities. Adult male and female humpback whales average 14 and 15 m (46 and 49 ft) in length, respectively (Wynne 1997). Most individual humpback whales can be identified by distinctive patterns on the tail flukes. 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).

During the summer months, humpback whales are common in Prince William Sound and along the south side of the Alaska Peninsula to Unimak Pass. Humpback whales are less common in the Bering Sea and rare in the Chukchi Sea. 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, Allen and Angliss 2010). Recently there have been sightings of humpback whales in the Chukchi Sea and a single sighting in the Beaufort Sea (Green et al. 2007). Haley et al. (2010) reported four humpback whales during vessel-based surveys in the Chukchi Sea in 2007 and two humpback whale sighting during 2008 operations. Small numbers of humpback whales could occur within or near the project area in the Chukchi Sea.

Seals

Bearded Seal (Erignathus barbatus)

Bearded seals are typically associated with sea ice and have a circumpolar distribution (Burns 1981b). They have occasionally been reported to maintain breathing holes in sea ice and broken areas within the pack ice, particularly if the water depth is <200 m (e.g., Harwood et al. 2005). Bearded seals apparently also feed on ice-associated organisms when they are present, and this allows a few bearded seals to live in areas where water depth is considerably greater than 200 m (Cameron et al. 2009). During the summer period, bearded seals occur mainly in relatively shallow areas because they are predominantly benthic feeders (Burns 1981b). No reliable estimate of bearded seal abundance is available for the Chukchi Sea (Allen and Angliss 2010). The Alaska stock of bearded seals, part of the Beringia distinct population segment, has been proposed by NMFS for listing as threatened under the ESA (NMFS 2010a).

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

In Alaskan waters, bearded seals occur over the continental shelves of the Bering, Chukchi, and Beaufort Seas (Burns 1981b). The Alaska stock of bearded seals is likely greater than 155,000 (Beringia DPS, NMFS 2010a) may consist of 250,000–300,000 individuals (Popov 1976; 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 since these densities were not adjusted for haulout behavior. Bearded seals are common in offshore pack ice, but there have also been high bearded seal numbers observed near the shore south of the project area near Kivalina. Haley et al. (2010) reported bearded seal densities ranging from 0.01 to 0.09 seals/km^2 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 since the latter densities were based on aerial surveys of seals on sea ice in late May and early June.

Bearded seals are likely to be encountered during the planned activities in the Chukchi Sea and greater numbers of bearded seals are likely to be encountered if the ice edge is present nearby.

Spotted Seal (Phoca largha)

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

An early estimate of the size of the world population of spotted seals was 370,000–420,000, and the size of the Bering Sea population, including animals in Russian waters, was estimated to be 200,000–250,000 animals (Bigg 1981). The total number of spotted seals that currently inhabit Alaskan waters is not known (Allen and Angliss 2010), but the estimate is most likely between several thousand and several tens of thousands (Rugh et al. 1997). During the summer, spotted seals are found in Alaska from Bristol Bay through western Alaska to the Chukchi and Beaufort seas. The ADF&G placed satellite transmitters on 4 spotted seals and estimated that the proportion of seals hauled out was 6.8%. Based on an actual minimum count of 4145 hauled out seals, Allen and Angliss (2010) estimated the Alaskan population at 59,214 animals. The Alaska stock of spotted seals is not classified as endangered, threatened, or as a strategic stock by NMFS (Allen and Angliss 2010), although the southern distinct population segment (DPS) of spotted seals was recently listed as a threatened species, it occurs entirely outside of U.S. waters.

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

In the Chukchi Sea, Kasegaluk Lagoon and Icy Cape are important areas for spotted seals. Spotted seals haul out in this region from mid-July until freeze-up in late October or November. Frost et al. (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, Lowry et al. (1998) reported that spotted seals tagged at Kasegaluk Lagoon spent 94 percent 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. Few spotted seals are expected to occur near the planned activities in the Chukchi Sea.

Ringed Seal (*Phoca hispida*)

Ringed seals have a circumpolar distribution and occur in all seas of the Arctic Ocean (King 1983). They are closely associated with ice, and in the summer they often occur along the receding ice edges or farther north in the pack ice. In the North Pacific, they occur in the southern Bering Sea and range south to the seas of Okhotsk and Japan. They are found throughout the Beaufort, Chukchi, and Bering seas (Allen and Angliss 2010). The Alaska stock, part of the Arctic subspecies of ringed seal, has been proposed for listing as threatened under the ESA (NMFS 2010b).

Ringed seals are year-round residents in the Chukchi and Beaufort seas and the ringed seal is the most frequently encountered seal species in the area. During winter, ringed seals occupy landfast ice and offshore pack ice of the Bering, Chukchi and Beaufort seas. In winter and spring, the highest densities of ringed seals are found on stable shorefast ice. However, in some areas where there is limited fast ice but wide expanses of pack ice, including the Beaufort Sea, Chukchi Sea and Baffin Bay, total numbers of ringed seals on pack ice may exceed those on shorefast ice (Burns 1970; Stirling et al. 1982; Finley et al. 1983). Ringed seals maintain breathing holes in the ice and occupy lairs in accumulated snow (Smith and Stirling 1975). They give birth in lairs from mid-March through April, nurse their pups in the lairs for 5–8 weeks, and mate in late April and May (Smith 1973; Hammill et al. 1991; Lydersen and Hammill 1993).

No estimate for the size of the Alaska ringed seal stock is currently available (Allen and Angliss 2010). 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). In the Chukchi Sea, Bengtson et al. (2005) reported ringed seal densities offshore from Shishmaref to Barrow ranging from 0.4 to 3.7 seals/km^2 and estimated the total Chukchi Sea population at 245,048 animals in 1999. Densities were higher in nearshore than offshore locations. During vessel-based observations from industry activities in the Chukchi Sea, Haley et al. (2010) reported seal densities (composed largely of ringed seals) from 0.07 to 0.74 seals/km^2 in summer and fall, respectively.

Ringed seal will likely be the most abundant marine mammal species encountered in the areas of the planned activities in the Chukchi Sea.

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) suggested 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 2006–2008 with only two sightings among 1390 seal sightings identified to species (Haley et al. 2010). Ribbon seals are unlikely to occur in the vicinity of the planned activities in the Chukchi Sea.

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 site clearance and shallow hazards surveys and geotechnical soil investigations in the Chukchi Sea during August–November, 2011.

The operations outlined in sections 1 and 2 have the potential to take marine mammals by harassment. Sounds that may “harass” marine mammals will include pulsed sounds generated by the airguns used during the site surveys as well as continuous sounds generated by the geotechnical soil investigations. The effects will depend on the species of cetacean or pinniped, the behavior of the animal at the time of reception of the stimulus, as well as the distance and received level of the sound (see § VII). Disturbance reactions are likely to vary among some of the marine mammals in the general vicinity of the sound source. No “take” by serious injury is anticipated, given the nature of the planned operations and the mitigation measures that are planned (see § XI, “Mitigation Measures”). No lethal takes are expected.

VI. NUMBERS OF MARINE MAMMALS THAT MAY BE TAKEN

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

All anticipated takes would be “takes by harassment”, involving temporary changes in behavior. The mitigation measures to be applied will minimize the possibility of injurious takes. (However, there is no specific information demonstrating that injurious “takes” would occur even in the absence of the planned mitigation measures.) In the sections below, we describe methods to estimate “take by harassment” and present estimates of the numbers of marine mammals that might be affected during the planned activities in the Chukchi Sea. The estimates are based on data obtained during marine mammal surveys in and near the proposed survey areas and on estimates of the sizes of the areas where effects may occur. In some cases, these estimates were made from data collected in regions, habitats, or seasons that differ from the planned activity areas. Adjustments to reported population or density estimates were made to account for these differences insofar as possible.

The main sources of distributional and numerical data used in deriving the estimates are described in the next subsection. There is some uncertainty about the representativeness of those data and the assumptions used below to estimate the potential "take by harassment". However, the approach used here is the best available at this time.

"Take by Harassment" has been calculated by multiplying the expected densities of marine mammals that may occur near the planned activities by the area of water likely to be exposed to pulsed sound levels of ≥160 dB re 1 μPa (rms) and continuous sound levels ≥120 dB re 1 μPa (rms).

Marine Mammal Density Estimates

This section describes the estimated densities of marine mammals that may occur in the areas where activities are planned. The area of water that may be ensonified by pulsed sounds to ≥160 dB or continuous sounds to ≥120 dB is described in the sub-section below. There is no evidence that avoidance at received sound levels of ≥160 dB would have significant effects on individual animals or that the subtle changes in behavior or movements would "rise to the level of taking" according to guidance by the NMFS (NMFS 2001). Any changes in behavior caused by sounds at or near the 160 dB or 120 dB levels would likely fall within the normal variation in such activities that would occur in the absence of the planned activities.

Marine mammal densities near the planned activities in the Chukchi Sea are likely to vary by season, and habitat. Therefore, densities have been derived for two time periods, the summer period, including July and August, and the fall period, including September and October. Animal densities encountered in the Chukchi Sea during both of these time periods will further depend on whether they are occurring in open water or near the ice margin. Vessel and equipment limitations will result in very little activity occurring in or near sea ice, however, if ice is present near the areas of activity some sounds produced by the activities may remain above disturbance threshold levels in ice margin habitats. Therefore, open water densities have been used to estimate potential "take by harassment" in 90% of the area expected to be ensonified above disturbance thresholds while ice margin densities have been used in the remaining 10% of the ensonified area.

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, several density estimates were available, and in those cases the mean and maximum estimates were determined from the reported results. In other cases, no applicable estimate (or perhaps a single estimate) was available, so correction factors were used to arrive at "average" and "maximum" estimates. These are described in detail in the following sections.

Detectability bias [*f(0)*], is associated with diminishing sightability with increasing lateral distance from the trackline. Availability bias [*g(0)*] refers to the fact that there is <100% probability of sighting an animal that is present on the survey trackline. Some sources of densities used below included these correction factors in their reported densities. In other cases the best available correction factors were applied to reported results when they had not been included in the reported analyses (e.g. Moore et al. 2000b).

Cetaceans

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.

Belgua Whale

Summer densities of belugas in offshore waters of the Chukchi Sea are expected to be low, with higher densities in ice-margin and nearshore areas. 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 >14,000 km of on-transect effort, only 2 of which were offshore (COMIDA 2009). One of the three nearshore sightings was of a large group (~275 individuals on July 12, 2009) of migrating belguas along the coastline just north of Peard Bay. Additionally, only one beluga sighting was recorded during >61,000 km of visual effort during good visibility conditions from industry vessels operating largely in offshore areas of the Chukchi Sea in September–October of 2006–2008 (Haley et al. 2010). 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 have previously been calculated from data in Moore et al. (2000b). However, more recent data from COMIDA aerial surveys during 2008-2010 are now available. Effort and sightings reported by Clarke and Ferguson (*in prep.*) were used to calculate the average open-water density estimate. Clarke and Ferguson (*in prep*) reported two on-transect beluga sightings (5 individuals) during 11,985 km of on-transect effort in waters 36-50 m deep in the Chukchi Sea during July and August. The mean group size of these two sightings is 2.5. A *f(0)* value of 2.841 and *g(0)* value of 0.58 from Harwood et al. (1996) were also used in the density 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 open-water and ice-margin habitats. Specific data on the relative abundance of beluga whales in open-water versus ice-margin habitats during the summer in the Chukchi Sea are not available. However, belugas are commonly associated with ice, so an inflation factor of 4 was used to estimate the average ice-margin density from the open-water density. Very low densities observed from vessels operating in the Chukchi Sea during non-seismic periods and locations in July–August of 2006–2008 (0.0–0.0001/km^2; Haley et al. 2010) also suggest the number of beluga whales likely to be present near the planned activities will not be large.

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 (Allen and Angliss 2010). However, there were no beluga sightings reported during >18,000 km of vessel based effort in good visibility conditions during 2006–2008 industry operations in the Chukchi Sea (Haley et al. 2010). Densities derived from survey results in the northern Chukchi Sea in Clarke and Ferguson (*in prep*) were used as the average density for open-water fall season estimates (see Table 4). Clarke and Ferguson (*in prep*) reported 3 beluga sightings (6 individuals) during 10,036 km of on-transect effort in water depths 36–50 m. The mean group size of those three sightings is 2. 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 same inflation factor of 2 used for summer densities was used to estimate the maximum density that may occur in both open-water and ice-margin habitats in the fall. Moore et al. (2000b) reported lower than expected beluga sighting rates in open-water during fall surveys in the Beaufort and Chukchi seas, so an inflation value of 4 was used to estimate the average ice-margin density from the open-water density. Based on the lack of any beluga sightings from vessels operating in the Chukchi Sea during non-seismic periods and locations in Sep–Oct of 2006–2008 (Haley et al. 2010), the relative low densities shown in Table 3 are consistent with what is likely to be observed form vessels during the planned operations.

Table 3. Expected densities of cetaceans and seals in areas of the Chukchi Sea, Alaska, for the planned summer (July–August) period. Species listed under the U.S. ESA as Endangered are in italics.

Species	**Open Water**		**Ice Margin**	
	Average Density (# / km^2)	**Maximum Density (# / km^2)**	**Average Density (# / km^2)**	**Maximum Density (# / km^2)**
Odontocetes				
Monodontidae				
Beluga	0.0010	0.0020	0.0040	0.0080
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	0.0015	0.0011	0.0015
Mysticetes				
Bowhead whale	0.0013	0.0026	0.0013	0.0026
Fin whale	0.0001	0.0004	0.0001	0.0004
Gray whale	0.0258	0.0516	0.0258	0.0516
Humpback whale	0.0001	0.0004	0.0001	0.0004
Minke whale	0.0001	0.0004	0.0001	0.0004
Pinnipeds				
Bearded seal [a]	0.0107	0.0203	0.0142	0.0270
Ribbon seal	0.0005	0.0020	0.0005	0.0020
Ringed seal [a]	0.3668	0.6075	0.4891	0.8100
Spotted seal	0.0073	0.0122	0.0098	0.0162

[a] Maximum density estimate available from the data source was used.

Table 4. Expected densities of cetaceans and seals in areas of the Chukchi Sea, Alaska, for the fall (September–October) period. Species listed under the U.S. ESA as Endangered are in italics.

Species	**Open Water**		**Ice Margin**	
	Average Density (# / km^2)	**Maximum Density (# / km^2)**	**Average Density (# / km^2)**	**Maximum Density (# / km^2)**
Odontocetes				
Monodontidae				
Beluga	0.0015	0.0030	0.0060	0.0120
Narwhal	0.0000	0.0000	0.0000	0.0001
Delphinidae				
Killer whale	0.0001	0.0004	0.0001	0.0004
Phocoenidae				
Harbor porpoise	0.0001	0.0011	0.0001	0.0011
Mysticetes				
Bowhead whale	0.0219	0.0438	0.0438	0.0876
Fin whale	0.0001	0.0004	0.0001	0.0004
Gray whale	0.0080	0.0160	0.0080	0.0160
Humpback whale	0.0001	0.0004	0.0001	0.0004
Minke whale	0.0001	0.0004	0.0001	0.0004
Pinnipeds				
Bearded seal [a]	0.0107	0.0203	0.0142	0.0270
Ribbon seal	0.0005	0.0020	0.0005	0.0020
Ringed seal [a]	0.2458	0.4070	0.3277	0.5427
Spotted seal	0.0049	0.0081	0.0065	0.0108

[a] Maximum density estimate available from the data source was used.

Bowhead Whales

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 10,684 km of on-transect effort in the Chukchi Sea by Moore et al. (2000b). Aerial surveys in 2008–2010 by the NMML as part of the COMIDA project reported six sightings during 25,781 km of on-transect effort (Clarke and Ferguson 2011). Two of the six sightings were in waters ≤35 m deep and the remaining four sightings were in waters 51-200 m deep. Bowhead whales were also rarely sighted in July–August of 2006–2008 during aerial surveys of the Chukchi Sea coast (Thomas et al. 2010). This is consistent with movements of tagged whales (ADFG 2010) 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 summer bowhead whale density in the Chukchi Sea was calculated by assuming there was one bowhead sighting during the 11,985 km of survey effort in waters 36-50 m deep in the Chukchi Sea during July–August reported in Clarke and Ferguson (*in prep*), although no bowheads were actually observed during those surveys. The mean group size from September–October sightings reported in Clarke and Ferguson (*in prep*) is 1.1, and this was also used in the calculation of summer densities. The group size 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 (Table 3). The CV of group size and standard errors reported in Thomas et al (2002) for *f(0)* and *g(0)* correction factors suggest that an inflation factor of 2 is appropriate for estimating the maximum density from the average density. 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. 2010) ranged from 0.0001–0.0007/km^2 with a maximum 95 percent confidence interval (CI) of 0.0029/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.

During the fall, bowhead whales that summered in the Beaufort Sea and Amundsen Gulf migrate west and south to their wintering grounds in the Bering Sea, making it more likely that bowheads will be encountered in the Chukchi Sea at this time of year. Moore et al. (2000b; Table 8) reported 34 bowhead sightings during 44,354 km of on-transect survey effort in the Chukchi Sea during September–October. Thomas et al. (2010) also reported increased sightings on coastal surveys of the Chukchi Sea during September and October of 2006–2008. GPS tagging of bowheads appear to show that migration routes through Chukchi Sea are more variable than through the Beaufort Sea (Quakenbush et al. 2010). Some of the routes taken by bowheads remain well north of the planned 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 (Quakenbush et al. 2010). Clarke and Ferguson (*in prep*) reported 14 sightings (15 individuals) during 10,036 km of on transect aerial survey effort in 2008-2010. The mean group size from those sightings is 1.1. The same *f(0)* and *g(0)* values that were used for the summer estimates above were used for the fall estimates (Table 4). 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 (Table 4). Densities from vessel based surveys in the Chukchi Sea during non-seismic periods and locations in September–October of 2006–2008 (Haley et al. 2010) ranged from 0.0003/km^2 to 0.0044/km^2 with a maximum 95 percent CI of 0.0419 km^2. This suggests the densities used in the calculations and shown in Table 4 are somewhat higher than are likely to be observed from vessels near the area of planned operations.

Gray Whale

Gray whale densities are expected to be much higher in the summer months than during the fall. Moore et al. (2000b) found the distribution of gray whales in the planned operational area was scattered and generally limited to nearshore areas where most whales were observed in water less than 35 m deep. Thomas et al. (2010) also reported substantial declines in the sighting rates of gray whales in the fall. The average open-water summer density (Table 3) was calculated from effort and sightings reported by Clarke and Ferguson (*in prep*) for water depths 36–50 m including 54 sightings (73 individuals) during 11,985 km of on-transect effort. The average group size of those sightings is 1.35. 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. Similar to beluga and bowhead whales, an inflation factor of 2 was used to estimate the maximum densities from average densities in both habitat types and seasons. Gray whales are not commonly associated with sea ice, but may be present near it, so the same densities were used for ice-margin habitat as were derived for open-water habitat during both seasons. Densities from vessel based surveys in the Chukchi Sea during non-seismic periods and locations in July–August of 2006–2008 (Haley et al. 2010) ranged from 0.0021/km^2 to 0.0080/km^2 with a maximum 95 percent CI of 0.0336 km^2.

In the fall, gray whales may be dispersed more widely through the northern Chukchi Sea (Moore et al. 2000b), but overall densities are likely to be decreasing as the whales begin migrating south. A density calculated from effort and sightings (15 sightings [19 individuals] during 10,036 km of on-transect effort) in water 36–50 m deep during September–October reported by Clarke and Ferguson (*in prep*) was used as the average estimate for the Chukchi Sea during the fall period (Table 4). The corresponding group size value of 1.26, along with the same *f(0)* and *g(0)* values described above were also used in the calculation. Densities from vessel based surveys in the Chukchi Sea during non-seismic periods and locations in July–August of 2006–2008 (Haley et al. 2010) ranged from $0.0026/km^2$ to $0.0042/km^2$ with a maximum 95 percent CI of $0.0277\ km^2$.

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. 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 $0.0008/km^2$ to $0.0015/km^2$ with a maximum 95 percent CI of $0.0079/km^2$ (Haley et al. 2010). The average of those three years ($0.0011/km^2$) was used as the average open-water density estimate while the high value ($0.0015/km^2$) was used as the maximum estimate (Table 3). 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 than the summer months and ranged from $0.0002/km^2$ to $0.0010/km^2$ with a maximum 95 percent CI of $0.0093/km^2$. The average of those three years ($0.0001/km^2$) was again used as the average density estimate and the high value $0.0011/km^2$ was used as the maximum estimate (Table 4).

Other Cetaceans

The remaining five cetacean species that could be encountered in the Chukchi Sea during Statoil's planned activities 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 planned activities. George and Suydam (1998) reported killer whales, Brueggeman et al. (1990) and Haley et al. (2010) reported minke whale, and COMIDA (2009) and Haley et al. (2010) reported fin whales. 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) indicated a small number of extralimital sightings in the Chukchi Sea.

Pinnipeds

Three species of pinnipeds under NMFS jurisdiction are likely to be encountered in the Chukchi Sea during Statoil's planned activities: ringed seal, bearded seal, and spotted seal. Each of these species, except for 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) for ringed and bearded seals during most seasons. 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. However, satellite tagging has shown that they sometimes undertake long excursions into offshore waters during summer (Lowry et al. 1994, 1998). Ribbon seals have been reported in very small numbers within the Chukchi Sea by observers on industry vessels (Patterson et al. 2007, Haley et al. 2010).

Ringed and Bearded Seals

Ringed seal and bearded seal "average" and "maximum" summer ice-margin densities (Table 3) were taken from Bengtson et al. (2005) who conducted spring surveys in the offshore pack ice zone (zone 12P) of the northern Chukchi Sea. However, a correction for bearded seal availability bias, *g(0)*, based on haulout and diving patterns was not available and used in the reported densities. 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 both seasons for both species. The fall density of ringed seals in the 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 also 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 0.0158/km^2 to 0.0687/km^2 with a maximum 95 percent CI of 0.1514/km^2 (Haley et al. 2010). These estimates are lower than those made by Bengtson et al. (2005) which is not surprising given the different survey methods and timing.

Spotted Seal

Little information on spotted seal densities in offshore areas of the Chukchi Sea is available. 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 2). Chukchi Sea spotted seal abundance was estimated by assuming that 8 percent 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 (Allen and Angliss 2010), 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 in offshore areas were estimated to be 2/3 of the summer densities.

Ribbon Seal

Two ribbon seal sightings were reported during industry vessel operations in the Chukchi Sea in 2006–2008 (Haley et al. 2010). The resulting density estimate of 0.0005/km^2 was used as the average density and 4 times that was used as the maximum for both seasons and habitat zones.

Area Potentially Exposed to Sounds ≥160 dB or ≥120 dB re 1 µPa (rms)

Shallow Hazards and Site Clearance Surveys

Statoil has contracted with Gardline CGGVeritas who will use their vessel M/V *Duke* to perform the site surveys in the Chukchi Sea (see Appendix A for vessel specifications). Site surveys will primarily occur on Statoil leases, with some overlap onto neighboring leases or unleased acreage in order to provide uniform coverage of the area. A coarse grid of data using all acoustics sources (including the 4×10 in^3 airgun cluster) will be collected across the rectangular site survey areas covering Statoil's leases shown in Figure 1. More detailed data, again using all acoustics sources, will be collected using closely spaced lines at ~5 potential exploration drilling locations on Statoil's leases. In total, a maximum of 2500 km of survey line would be surveyed on or near Statoil leases covering a total area of ~665 km^2.

A 4×10 in^3 airgun cluster will be used to obtain geological data during the site surveys. A similar airgun cluster was measured by Shell in 2009 during shallow hazards surveys on their nearby Burger prospect (Reiser et al. 2010). The measurements resulted in 90th percentile propagation loss equations of $RL = 218.0 - 17.5 \mathrm{Log}R - 0.00061R$ for a 4×10 in^3 airgun cluster and $RL = 204.4 - 16.0 \mathrm{Log}R - 0.00082R$

for a single 10 in^3 airgun (where RL = received level and R = range). For use in estimating potential harassment takes in this application, as well as for mitigation radii to be implemented by MMOs prior to SSV measurements (see §XI and §XIII), ranges to threshold levels from the 2009 measurements were increased by 25% as a precautionary approach (Table 1). The ≥160 dB distance is therefore estimated to be 2.25 km from the source. Adding a 2.25 km perimeter to the two site survey areas shown in Fig.1 results in an estimated area of 1037 km^2 being exposed to ≥160 dB.

Geotechnical Soil Investigations

Geotechnical soil investigations on the Statoil leases and leases jointly owned with CPAI will involve completing 3–4 boreholes at up to 8 total prospective drilling locations for an expected maximum of 29 boreholes. The 3–4 boreholes completed at each drilling location will be positioned in a square or triangle formation, roughly 100 m on each side. As described in § I, the sounds produced by soil investigation equipment are estimated to fall below 120 dB at a distance of 7.5 km. Buffering 4 core sites spaced 100 m apart with the 7.5 km 120 dB distance results in a total area of 180 km^2. The total area exposed to sounds ≥120 dB by soil investigations at the 8 prospective drilling locations will therefore be 1440 km^2.

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) by pulsed airgun sounds and to ≥120 dB re 1 µPa (rms) by continuous sounds during geotechnical soil investigations. 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 those sound levels.

The number of individuals of each species potentially exposed to received levels of pulsed sounds ≥160 dB re 1 µPa (rms) or to ≥120 dB re 1 µPa (rms) by continuous sounds 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 pulsed airgun sounds ≥160 dB re 1 µPa (rms). Thus, these calculations actually estimate the number of individuals potentially exposed to the specified sounds levels that would occur if there were no avoidance of the area ensonified to that level.

Site survey and geotechnical soil investigations are planned to occur primarily in August and September, with the potential to continue into mid-November, if necessary and weather permitting. For the purposes of assigning activities to the summer (August) and fall (September–October) periods for which densities have been estimated above, we have assumed that half of the operations will occur during the summer period and half will occur in the fall period. Additionally, the planned activities cannot be completed in or near significant amounts of sea ice, so 90% of the activity each season (and associated ensonified areas) has been multiplied by the open-water densities described above, while the remaining 10% of activity has been multiplied by the ice-margin densities.

Species with an estimated average number of individuals exposed equal to zero are included below for completeness, but are not likely to be encountered.

Shallow Hazards and Site Clearance Surveys

The estimated numbers of marine mammals potentially exposed to airgun sounds with received levels ≥160 dB (rms) from site surveys on Statoil's leases are shown in Table 5. The average and maximum estimates of the number of individual bowhead whales exposed to received sound levels ≥160 dB are 11 and 22, respectively. The average estimate for gray whales is slightly greater at 18, while few belugas are expected to be exposed. (Table 5). Few other cetaceans are likely to be exposed to airgun sounds ≥160 dB, but maximum estimates have been included to account for chance encounters.

Ringed seals are expected to be the most abundant animal in the Chukchi Sea during this period and the average and maximum estimates of the number exposed to ≥160 dB by site survey activities are 337 and 557, respectively (Table 5). Estimated exposures of other seal species are substantially below those for ringed seals (Table 5).

Geotechnical Soil Investigations

The estimated numbers of marine mammals potentially exposed to continuous sounds with received levels ≥120 dB (rms) from geotechnical soil investigations on Statoil's leases and jointly owned leases are shown in Table 6. The average and maximum estimates of the number of individual bowhead whales exposed to received sound levels ≥120 dB are 15 and 30, respectively. The average estimate for gray whales is slightly larger at 26 individuals (Table 6). Few other cetaceans are likely to be exposed to soil investigation sounds ≥120 dB.

The average and maximum estimates of the number of ringed seals potentially exposed to ≥120 dB by soil investigation activities are 467 and 774, respectively (Table 6). Estimated exposures of other seal species are substantially below those for ringed seals (Table 6).

Conclusions

Cetaceans

Effects on cetaceans are generally expected to be restricted to avoidance of the area around the planned activities and short-term changes in behavior, falling within the MMPA definition of "Level B harassment".

The best (average) estimate of the number of individual bowheads exposed to airgun sounds ≥160 dB and soil investigation sounds ≥120 dB from Statoil site surveys and geotechnical soil investigations is 26 (Tables 5 and 6). The same pair of estimates for gray and beluga whales are 44 and 4, respectively (Tables 5 and 6).

The estimated 26 total bowheads exposed by all proposed by activities is <1% of the 2011 Bering-Chukchi-Beaufort population of 14,731 assuming 3.4% annual population growth from the 2001 estimate of 10,545 animals (Zeh and Punt 2005). The similar estimated totals for beluga and gray whales also represent <1% of their respective populations. Chance encounters with small numbers of other cetacean species are not likely, but possible.

Pinnipeds

The best (average) estimate of the number of individual ringed seals exposed to airgun sounds ≥160 dB and soil investigation sounds ≥120 dB from Statoil site surveys and geotechnical is 804 (Tables 5 and 6). This is <1% of the estimated eastern Chukchi Sea population of >200,000 (Bengtson et al. 2005). The total numbers of bearded and spotted seals potentially exposed to received sounds at the specified levels from all proposed activities, 27 and 16, respectively, are also <1% of their populations. Few, if any, ribbon seals are expected to be encountered.

Table 5. Estimates of the numbers of marine mammals in Areas where maximum received sound levels in the water would be ≥160 dB in summer (Aug) and Fall (Sep–Oct) periods during Statoil's planned site surveys in the Chukchi Sea, Alaska. Not all marine mammals will change their behavior when exposed to these sound levels.

	Number of Individuals Exposed to Sound Levels ≥160 dB									
	Summer				**Fall**					
	Open Water [a]		**Ice Margin** [b]		**Open Water** [a]		**Ice Margin** [b]		**Total**	
Species	**Avg.**	**Max.**	**Avg.**	**Max.**	**Avg.**	**Max.**	**Avg.**	**Max.**	**Avg.**	**Max.**
Odontocetes										
Monodontidae										
Beluga	0	1	0	0	1	1	0	0	2	5
Narwhal	0	0	0	0	0	0	0	0	0	5
Delphinidae										
Killer whale	0	0	0	0	0	0	0	0	0	5
Phocoenidae										
Harbor porpoise	1	1	0	0	0	1	0	0	1	5
Mysticetes										
Bowhead whale	1	1	0	0	10	20	0	0	11	22
Fin whale	0	0	0	0	0	0	0	0	0	5
Gray whale	12	24	1	3	4	7	1	3	18	37
Humpback Whale	0	0	0	0	0	0	0	0	0	5
Minke whale	0	0	0	0	0	0	0	0	0	5
Pinnipeds										
Bearded seal	5	9	1	1	5	9	1	1	11	22
Ribbon seal	0	1	0	0	0	1	0	0	1	5
Ringed seal	171	283	25	42	115	190	25	42	337	557
Spotted seal	3	6	1	1	2	4	1	1	7	11

[a] Open water regions for the Chukchi Sea are considered to be 90% of the survey lines.

[b] Ice Margin regions for the Chukchi Sea are considered to be 10% of the survey lines.

Table 6. Estimates of the numbers of marine mammals in areas where maximum received sound levels in the water would be ≥120 dB in summer (Aug) and Fall (Sep–Oct) periods during Statoil's planned geotechnical soil investigations in the Chukchi Sea, Alaska. Not all marine mammals will change their behavior when exposed to these sound levels.

	Number of Individuals Exposed to Sound Levels ≥120 dB									
	Summer				**Fall**					
	Open Water [a]		**Ice Margin [b]**		**Open Water [a]**		**Ice Margin [b]**		**Total**	
Species	**Avg.**	**Max.**	**Avg.**	**Max.**	**Avg.**	**Max.**	**Avg.**	**Max.**	**Avg.**	**Max.**
Odontocetes										
Monodontidae										
Beluga	1	1	0	1	1	2	0	1	2	5
Narwhal	0	0	0	0	0	0	0	0	0	5
Delphinidae										
Killer whale	0	0	0	0	0	0	0	0	0	5
Phocoenidae										
Harbor porpoise	1	1	0	0	0	1	0	0	1	5
Mysticetes										
Bowhead whale	1	2	0	0	14	28	0	0	15	30
Fin whale	0	0	0	0	0	0	0	0	0	5
Gray whale	17	33	2	4	5	10	2	4	26	51
Humpback Whale	0	0	0	0	0	0	0	0	0	5
Minke whale	0	0	0	0	0	0	0	0	0	5
Pinnipeds										
Bearded seal	7	13	1	2	7	13	1	2	16	30
Ribbon seal	0	1	0	0	0	1	0	0	1	5
Ringed seal	238	394	35	58	159	264	35	58	467	774
Spotted seal	5	8	1	1	3	5	1	1	9	15

[a] Open water regions are considered to be 90% of the coring areas.

[b] Ice Margin regions are considered to be 10% of the coring areas.

VII ANTICIPATED IMPACT ON SPECIES OR STOCKS

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

This section summarizes the potential impacts on marine mammals of the acoustics sources proposed for use during the planned operations. Note that for completeness, examples or information are sometimes included for species that are not likely to be present in the proposed survey area.

Summary of potential effects of airgun sounds

The effects of sounds from airguns might include one or more of the following: tolerance, masking of natural sounds, behavioral disturbance, and at least in theory, temporary or permanent hearing impairment, or non-auditory physical effects (Richardson et al. 1995a). *In theory* is added because it is unlikely that temporary or especially permanent hearing impairment and non-auditory physical effects would occur.

Tolerance

Numerous studies have shown that pulsed sounds from airguns are often readily detectable in the water at distances of many kilometers. 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 B, Section 5). That is often true even in cases when the pulsed sounds must be readily audible to the animals based on measured received levels and the hearing sensitivity of that mammal group. Although various baleen whales, toothed whales, and (less frequently) pinnipeds have been shown to react behaviorally to airgun pulses under some conditions, at other times mammals of all three types have shown no overt reactions. In general, pinnipeds, small odontocetes, and sea otters seem to be more tolerant of exposure to airgun pulses than are baleen whales.

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 larger arrays of airguns than proposed in this project) on marine mammal calls and other natural sounds are expected to be limited, although there are very few specific data of relevance. Some whales are known to continue calling in the presence of seismic pulses. Their calls can be heard between the seismic pulses (e.g., Richardson et al. 1986; McDonald et al. 1995; Greene et al. 1999; Nieukirk et al. 2004). Although there has been one report that sperm whales cease calling when exposed to pulses from a very distant seismic ship (Bowles et al. 1994), a more recent study reports that sperm whales off northern Norway continued calling in the presence of seismic pulses (Madsen et al. 2002). That has also been shown during recent work in the Gulf of Mexico (Tyack et al. 2003). Bowhead whale calls are frequently detected in the presence of seismic pulses, although the number of calls detected may sometimes be reduced in the presence of airgun pulses (Richardson et al. 1986; Greene et al. 1999; Blackwell et al. 2009a). Bowhead whales in the Beaufort Sea may decrease their call rates in response to seismic operations, although movement out of the area might also have contributed to the lower call detection rate (Blackwell et al. 2009a,b). In contrast, Di Iorio and Clark (2009) found evidence of increased calling by blue whales during operations by a lower-energy seismic source, a sparker. Masking effects of seismic pulses are expected to be negligible given the low number of cetaceans expected to be exposed, the intermittent nature of seismic pulses and the fact that ringed seals (the most abundant species in the area) are not typically vocal during this period. Masking effects, in general, are discussed further in Appendix B, 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. Given the many uncertainties in predicting the quantity and types of impacts of noise on marine mammals, it is common practice to estimate how many mammals were present within a particular distance of industrial activities, or exposed to a particular level of industrial sound. That likely overestimates the numbers of marine mammals that are affected in some biologically-important manner.

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

Baleen Whales

Baleen whales generally tend to avoid operating airguns, but avoidance radii are quite variable among species, locations, whale activities, oceanographic conditions affecting sound propagation, etc. (reviewed in Richardson et al. 1995a; 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 B, baleen whales exposed to strong noise pulses from airguns may react by deviating from their normal migration route and/or interrupting their feeding and moving away. In the case of the migrating gray and bowhead whales, the observed changes in behavior appeared to be of little or no biological consequence to the animals. They simply avoided the sound source by displacing their migration route to varying degrees, but within the natural boundaries of the migration corridors.

Studies of gray, bowhead, and humpback whales have determined that received levels of pulses in the 160–170 dB re 1 µPa rms range seem to cause obvious avoidance behavior in a substantial fraction of the animals exposed. In many areas, seismic pulses from large arrays of airguns diminish to those levels at distances ranging from 4.5 to 14.5 km from the source. For the much smaller airgun array of this seismic survey distances to received levels in the 160–170 dB re 1 µPa rms range are 1200–435 m. Baleen whales within those distances may show avoidance or other strong disturbance reactions to the airgun array, however in the site clearance and shallow hazards survey area a limited number of baleen whales are expected to occur. 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 1 µPa rms.

Bowhead whales migrating west across the Alaskan Beaufort Sea in autumn, in particular, are unusually responsive, with avoidance occurring out to distances of 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) corroborates earlier evidence that, during the summer feeding season, bowheads are not as sensitive to seismic sources. In summer, bowheads typically begin to show avoidance reactions at a received level of about 160–170 dB re 1 µPa rms (Richardson et al. 1986; Ljungblad et al. 1988; Miller et al. 1999).

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

Few systematic data are available about reactions of toothed whales to noise pulses. Few studies similar to the more extensive baleen whale/seismic pulse work summarized above and (in more detail) in Appendix C have been reported for toothed whales. However, systematic work on sperm whales is underway (Tyack et al. 2003), and there is an increasing amount of information about responses of various odontocetes to seismic surveys based on monitoring studies (e.g., Stone 2003; Smultea et al. 2004; Moulton and Miller 2005; and many others as summarized in Appendix B, 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). The beluga may be a species that (at least at times) shows long-distance avoidance of seismic vessels. Aerial surveys during seismic operations in the southeastern Beaufort Sea recorded much lower sighting rates of beluga whales within 10–20 km of an active seismic vessel. These results were consistent with the low number of beluga sightings reported by observers aboard the seismic vessel, suggesting that some belugas might be avoiding the seismic operations at distances of 10–20 km (Miller et al. 2005).

Captive bottlenose dolphins and (of more relevance in this project) beluga whales exhibit changes in behavior when exposed to strong pulsed sounds similar in duration to those typically used in seismic surveys (Finneran et al. 2002, 2005). However, the animals tolerated high received levels of sound (pk–pk level >200 dB re 1 μPa) before exhibiting aversive behaviors.

Reactions of toothed whales 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 B). A ≥170 dB disturbance criterion (rather than ≥160 dB) is considered appropriate for delphinids (and pinnipeds), which tend to be less responsive than other cetaceans. However, based on the limited existing evidence, belugas should not be grouped with delphinids in the "less responsive" category.

Pinnipeds

Pinnipeds are not likely to show a strong avoidance reaction to the airgun sources that will be used. Visual monitoring from seismic vessels has shown only slight (if any) avoidance of airguns by pinnipeds, and only slight (if any) changes in behavior (see Appendix 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). 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 B, 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, and
- the level associated with the onset of TTS is often considered to be a level below which there is no danger of permanent damage.

NMFS is presently developing new noise exposure criteria for marine mammals that account for the now-available scientific data on TTS and other relevant factors in marine and terrestrial mammals

(NMFS 2005; D. Wieting in http://mmc.gov/sound/plenary2/pdf/ plenary2summaryfinal.pdf; Scholik-Schlomer *in press*). New science-based noise exposure criteria are also proposed by a group of experts in this field, based on an extensive review and syntheses of available data on the effect of noise on marine mammals (Southall et al., 2007) and this review seems to confirm that the current 180 dB and 190 dB are conservative.

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. In addition, many cetaceans are likely to show some avoidance of the area with high received levels of airgun sound (see above). In those cases, the avoidance responses of the animals themselves will reduce or (most likely) avoid any possibility of hearing impairment.

Non-auditory physical effects might also occur in marine mammals exposed to strong underwater pulsed sound. Possible types of non-auditory physiological effects or injuries that theoretically might occur in mammals close to a strong sound source include stress, neurological effects, bubble formation, and other types of organ or tissue damage. It is possible that some marine mammal species (i.e., beaked whales) may be especially susceptible to injury and/or stranding when exposed to strong pulsed sounds. However, as discussed below, there is no definitive evidence that any of these effects occur even for marine mammals in close proximity to large arrays of airguns and beaked whales do not occur in the present study area. It is unlikely that any effects of these types would occur during the present project given the brief duration of exposure of any given mammal, and the planned monitoring and mitigation measures (see below). The following subsections discuss in somewhat more detail the possibilities of TTS, permanent threshold shift (PTS), and non-auditory physical effects.

Temporary Threshold Shift (TTS)

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

For toothed whales exposed to single short pulses, the TTS threshold appears to be, to a first approximation, a function of the energy content of the pulse (Finneran et al. 2002, 2005). Given the available data, the received level of a single seismic pulse might need to be ~210 dB re 1 µPa rms (~221–226 dB pk–pk) in order to produce brief, mild TTS. Exposure to several seismic pulses at received levels near 200–205 dB (rms) might result in slight TTS in a small odontocete, assuming the TTS threshold is (to a first approximation) a function of the total received pulse energy. Seismic pulses with received levels of 200–205 dB or more are usually restricted to a radius of no more than 200 m around a seismic vessel operating a large array of airguns. For the smaller airgun array used in the proposed survey this radius will be <35 m.

For baleen whales, there are no data, direct or indirect, on levels or properties of sound that are required to induce TTS. However, no cases of TTS are expected given the small size of the sound source, and the strong likelihood that baleen whales (especially migrating bowheads) would avoid the approaching airguns (or vessel) before being exposed to levels high enough for there to be any possibility of TTS.

In pinnipeds, TTS thresholds associated with exposure to brief pulses (single or multiple) of underwater sound have not been measured. Initial evidence from prolonged exposures suggested that some pinnipeds may incur TTS at somewhat lower received levels than do small odontocetes exposed for similar durations (Kastak et al. 1999, 2005; Ketten et al. 2001; cf. Au et al. 2000). In the harbor seal, which is closely related to the ringed seal, TTS onset apparently occurs at somewhat lower received energy levels than for odontocetes.

A detailed overview of current available information is provided in Appendix B 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 B, Section 6).

It is highly unlikely that marine mammals could receive sounds strong enough (and over a sufficient duration) to cause permanent hearing impairment during a project employing the airgun sources planned here. In the proposed project, marine mammals are unlikely to be exposed to received levels of seismic pulses strong enough to cause 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 so in the case of the proposed project where the airgun configuration focuses most energy downward and the source vessels are moving at 4–5 knots.

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

Stranding and Mortality

Marine mammals close to underwater detonations of high explosive can be killed or severely injured, and the auditory organs are especially susceptible to injury (Ketten et al. 1993; Ketten 1995). Airgun pulses are less energetic and have slower rise times, and there is no proof that they can cause serious injury, death, or stranding even in the case of large airgun arrays (Appendix B, Section 6.3 provides additional details). However, the association of mass strandings of beaked whales with naval exercises and, in one case, a seismic survey, has raised the possibility that beaked whales exposed to strong pulsed sounds may be especially susceptible to injury and/or behavioral reactions that can lead to stranding. However, no beaked whales are found within this project area. The shallow water environment, small airgun arrays and planned monitoring and mitigation measures of the proposed survey are not expected to result in mortality of other marine mammal species.

Summary of potential effects of bathymetric sonar and echosounder signals

Bathymetric sonar equipment planned for use during the 2011 site clearance and shallow hazards survey include a dual-frequency side scan sonar (operating at 114 and 410 kHz), single-beam echo sounders (18 and 200 kHz), a multibeam echo sounder (200–400 kHz), and a high precision acoustic position system. These sonar devices emit very short pulses, depending on water depth. Most of the energy in the sound pulses emitted by bathymetric sonars is at moderately high frequencies. The beam from mulitbeam and side scan sonars is narrow in fore-aft extent and wider in the cross-track extent. Single beam units typically have a narrow conical beam project directly below the vessel. Any given mammal at depth near the trackline would be in the main beam for only a fraction of a second. Therefore, marine mammals that encounter these sonar devices at close range are unlikely to be subjected to repeated pulses because of the narrow fore–aft width of the beam, and will receive only limited amounts of pulse energy because of the short pulses. Similarly, Kremser et al. (2005) noted that the probability of a cetacean swimming through the area of exposure when a multibeam sonar emits a pulse is small. The animal would have to pass the transducer at close range and be swimming at speeds similar to the vessel in order to be subjected to sound levels that could cause TTS.

Navy sonars that have been linked to avoidance reactions and stranding of cetaceans (1) generally are more powerful than the equipment proposed for the current surveys, (2) have longer pulse duration, and (3) are directed close to horizontally vs. downward for the proposed equipment. The area of possible influence of the bathymetric sonar is much smaller—a narrow band oriented in the cross-track direction below the source vessel. In assessing the possible impacts of a similar multibeam system (the 15.5 kHz Atlas Hydrosweep multibeam bathymetric sonar), Boebel et al. (2004) noted that the critical sound pressure level at which TTS may occur is 203.2 dB re 1 μPa (rms). The critical region included an area of

43 m (141 ft) in depth, 46 m (151 ft) wide athwartship, and 1 m (3 ft) fore-and-aft. In the more distant parts of that (small) critical region, only slight TTS would be incurred.

Recent measurements of underwater sound propagation from equipment similar to that proposed for the 2011 surveys in the Chukchi Sea indicated relatively low sound levels and small sound radii. Underwater sound propagation ranged from 3 to 14 m (10 to 46 ft) for 160 dB rms sound radii, and from 306 to 1360 m (1004 to 4462 ft) for 120 dB rms sound radii during measurements in the Beaufort Sea in 2008 (Mouy and Hannay 2008; Zykov and Sneddon 2008). The small disturbance radii indicate that it would be extremely unlikely that any marine mammal would approach the operating bathymetric sonar close enough be affected in a biologically significant manner.

Masking

Marine mammal communications will not be masked appreciably by the bathymetric sonar signals given the low duty cycle of the sonar and the brief period when an individual mammal is likely to be within the sonar beam. Furthermore, the bathymetric sonar equipment proposed for the 2011 site surveys will not overlap with the predominant frequencies in baleen whale calls, further reducing any potential for masking in that group.

Odontocetes generally have better hearing capabilities at higher frequencies than baleen whales. Hearing range is known to extend to 80–150 kHz for some species. Some odontocetes are also capable of hearing low frequencies (e.g., <500 Hz) but their sensitivity at these low frequencies seems poor (Richardson et al. 1995a). Beluga whale is the only odontocete likely to occur in the proposed survey area, although harbor porpoise occurrence appears to be increasing in the Chukchi Sea and small numbers of harbor porpoise could occur in the survey area. The relatively high frequency of the proposed bathymetric sonar equipment will be above the best hearing frequencies of beluga whales and harbor porpoises, and will be unlikely to produce any masking effects for these species. Additionally these species would have to be very close to the sound source due to the small radii of sound propagation from these low energy sources.

Behavioral Responses

Behavioral reactions of free-ranging marine mammals to military and other sonars appear to vary by species and circumstance. Observed reactions have included silencing and dispersal by sperm whales (Watkins et al. 1985), increased vocalizations and no dispersal by pilot whales (Rendell and Gordon 1999), and previously mentioned beachings by beaked whales. Also, Navy personnel have described observations of dolphins bow-riding adjacent to bow-mounted mid-frequency sonars during sonar transmissions. During exposure to a 21–25 kHz whale-finding sonar with a source level of 215 dB re 1 µPa·m, gray whales showed slight avoidance (~200 m or 656 ft) behavior (Frankel 2005).

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

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

We are not aware of any data on the reactions of pinnipeds to sonar sounds at frequencies similar to those of the bathymetric sonar equipment. Additionally, pinniped hearing sensitivity is probably low at the relatively high frequencies of the proposed sonars. Based on observed pinniped responses to other types of pulsed sounds, and the likely brevity of exposure to the bathymetric sonar sounds, pinniped reactions to the sonar sounds are expected to be limited to startle or otherwise brief responses of no lasting consequence to the animals.

Polar bears would not occur below the sound source or elsewhere at sufficient depth to be in the main beam of the bathymetric sonar, so would not be affected by the sonar sounds. As noted earlier, NMFS (2001) has concluded that momentary behavioral reactions “do not rise to the level of taking”. Thus, brief exposure of cetaceans or pinnipeds to small numbers of signals from a bathymetric sonar system would not result in a “take” by harassment.

Hearing Impairment and Other Physical Effects

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

Summary of potential effects of sub-bottom profiler signals

A shallow, sub-bottom profiler (operating at 2–7 kHz) is planned for use during the 2011 site clearance and shallow hazards surveys. As discussed above for bathymetric sonar, the sonar equipment to be used for sub-bottom profiling during the proposed survey is relatively low energy compared to Navy sonar. Laurinolli et al. (2007) measured sound threshold levels for similar equipment (Datasonics CAP6000 profiler) in the Beaufort Sea in 2007. Underwater sound propagation ranged from 1 to 260 m (3 to 853 ft) for the 160 to 120 dB rms sound level radii.

Masking

Marine mammal communications will not be masked appreciably by the sub-bottom profiler signals given its relatively low duty cycle, directionality, and the brief period when an individual mammal is likely to be within its beam. The frequencies of sonar signals will not overlap with the predominant low frequencies in baleen whale calls, further reducing potential for masking for those species.

The only odontocetes likely to occur in the proposed survey area are beluga whale and possibly harbor porpoise. Belugas can be abundant in the Chukchi Sea during fall migration, however their migration path is not well known and appears diffuse, thus few belugas are expected to be observed near the proposed activities. Belugas can hear sounds ranging from 1.2 to 120 kHz with their peak sensitivity from ~10-15 kHz, which may overlap with some of the frequencies used by the sub-bottom profiling equipment (Fay 1988). However, the sub-bottom profiling equipment operates at low energy levels and sound propagation is low and unlikely to be audible to most beluga whales.

Behavioral Responses

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

Hearing Impairment and Other Physical Effects

Source frequencies of the sub-bottom profilers are much lower than those of the bathymetric sonar described above. As with the bathymetric sonar, the sub-bottom profiler pulses are brief and concentrated in a downward beam. A marine mammal would be in the beam of the sub-bottom profiler only briefly, reducing its received sound energy. Thus, it is unlikely that the sub-bottom profiler will produce pulse levels strong enough to cause hearing impairment or other physical injuries even in an animal that is (briefly) in a position near the source.

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

Summary of potential effects of geotechnical soil investigation activities

The potential effects of sounds from the planned geotechnical soil investigation activities might include one or more of the following: tolerance, masking of natural sounds, behavioral disturbance, and at least in theory, temporary or permanent hearing impairment, or non-auditory physical effects (Richardson et al. 1995a). It is unlikely that there would be any cases of temporary or especially permanent hearing impairment, or non-auditory physical effects given the low source levels produced by the equipment and vessels involved in this operation. There is not much information available specific to impacts from geotechnical soil investigations, however, the rotary drilling equipment used to collect the geotechnical samples is similar, but much smaller than, the type of equipment used during drilling. Therefore, we have provided below a summary of potential impacts based on results of studies of marine mammal reactions to sounds from drilling activities and other similar non-impulse sounds.

Tolerance

As described above in the same section regarding potential effects of airgun sounds, numerous studies have shown that underwater sounds from industry activities are often readily detectable in the water at distances of many kilometers. Numerous studies have also shown that marine mammals at distances more than a few kilometers away often show no apparent response to industry activities of various types, including drilling activities.

Disturbance Reactions

Baleen Whales

Southall et al. (2007–Appendix C) reviewed a number of papers describing the responses of marine mammals to non-pulsed sound. In general, little or no response was observed in animals exposed at received levels from 90-120 dB. Probability of avoidance and other behavioral effects increased when received levels were 120-160 dB. Some of the relevant reviews of Southall et al. (2007) are summarized below.

Baker et al. (1982) reported some avoidance by humpback whales to vessel noise when received levels were 110-120 dB rms, and clear avoidance at 120-140 dB (sound measurements were not provided by Baker but were based on measurements of identical vessels by Miles and Malme 1983).

Malme et al. (1983, 1984) used playback of sound from helicopter overflight and drilling rigs and platforms to study behavioral effects on migrating gray whales. Received levels exceeding 120 dB induced avoidance reactions. Malme et al. (1984) calculated 10%, 50%, and 90% probabilities of gray whale avoidance reactions at received levels of 110, 120, and 130 dB, respectively.

Malme et al. (1986) observed the behavior of feeding gray whales during four experimental playbacks of drilling sounds (50 to 315 Hz; 21- min overall duration and 10% duty cycle; source levels 156 to 162 dB). In two cases for received levels of 100 to 110 dB, no behavioral reaction was observed. Avoidance behavior was observed in two cases where received levels were 110 to 120 dB.

Richardson et al. (1990) performed 12 playback experiments in which bowhead whales in the Alaskan Arctic were exposed to drilling sounds. Whales generally did not respond to exposures in the 100 to 130 dB range, although there was some indication of minor behavioral changes in several instances.

Richardson et al. (1995b) reported changes in surfacing and respiration behavior, and the occurrence of turns during surfacing in bowhead whales exposed to playback of underwater sound from drilling activities. These subtle behavioral effects were temporary and localized, and occurred at distances up to 2-4 km.

McCauley et al. (1996) reported several cases of humpback whales responding to vessels in Hervey Bay, Australia. Results indicated clear avoidance at received levels between 118 to 124 dB in three cases for which response and received levels were observed/measured.

Palka & Hammond (2001) analyzed line transect census data in which the orientation and distance off transect line were reported for large numbers of Minke whales. Minor changes in locomotion speed, direction, and/or diving profile were reported at ranges from 563 to 717 m at RLs of 110 to 120 dB.

Frankel & Clark (1998) conducted playback experiments with wintering humpback whales using a single speaker producing a low-frequency “M-sequence” (sine wave with multiple-phase reversals) signal in the 60 to 90 Hz band with output of 172 dB at 1 m. For 11 playbacks, exposures were between 120 and 130 dB re: 1 µPa and included sufficient information regarding individual responses. During eight of the trials, there were no measurable differences in tracks or bearings relative to control conditions, whereas on three occasions, whales either moved slightly away from (n = 1) or towards (n = 2) the playback speaker during exposure. The presence of the source vessel itself had a greater effect than did the M-sequence playback.

Finally, Nowacek et al. (2004) used controlled exposures to demonstrate behavioral reactions of northern right whales to various nonpulse sounds. Playback stimuli included ship noise, social sounds of conspecifics, and a complex, 18-min “alert” sound consisting of repetitions of three different artificial signals. Ten whales were tagged with calibrated instruments that measured received sound characteristics and concurrent animal movements in three dimensions. Five out of six exposed whales reacted strongly to alert signals at measured received levels between 130 and 150 dB (i.e., ceased foraging and swam rapidly to the surface). Two of these individuals were not exposed to ship noise and the other four were exposed to both stimuli. These whales reacted mildly to conspecific signals. Seven whales, including the four exposed to the alert stimulus, had no measurable response to either ship sounds or actual vessel noise.

Toothed Whales

Most toothed whales have the greatest hearing sensitivity at frequencies much higher than that of baleen whales and may be less responsive to low-frequency sound commonly associated with industry activities. Richardson et al. (1995b) reported that beluga whales did not show any apparent reaction to playback of underwater drilling sounds at distances greater than 200-400 m. Reactions included slowing down, milling, or reversal of course after which the whales continued past the projector, sometimes within 50-100 m. The authors concluded (based on a small sample size) that playback of drilling sound had no biologically significant effects on migration routes of beluga whales migrating through pack ice and along the seaward side of the nearshore lead east of Pt. Barrow in spring.

At least six of 17 groups of beluga whales appeared to alter their migration path in response to underwater playbacks of icebreaker sound (Richardson et al. 1995b). Received levels from the icebreaker playback were estimated at 78-84 dB in the 1/3-octave band centered at 5000 Hz, or 8-14 dB above ambient. If beluga whales reacted to an actual icebreaker at received levels of 80 dB, reactions would be expected to occur at distances on the order of 10 km. Finley et al. (1990) also reported beluga avoidance of icebreaker activities in the Canadian High Arctic at distances of 35 to 50 km. In addition to avoidance, changes in dive behavior and pod integrity were also noted. Beluga whales have also been report to avoid active seismic vessels at distances of 10-20 km (Miller et al. 2005). It is likely that at least some beluga whales may avoid the vicinity of the proposed activities thus reducing the potential for exposure to high levels of underwater sound.

In reviewing responses of cetaceans with best hearing in mid-frequency ranges, which includes toothed whales, Southall et al. (2007) reported that combined field and laboratory data for mid-frequency cetaceans exposed to nonpulse sounds did not lead to a clear conclusion about received levels coincident with various behavioral responses. In some settings, individuals in the field showed profound (significant) behavioral responses to exposures from 90 to 120 dB, while others failed to exhibit such responses for exposure to received levels from 120 to 150 dB. Contextual variables other than exposure received level, and probable species differences, are the likely reasons for this variability. Context, including the fact that captive subjects were often directly reinforced with food for tolerating noise exposure, may also explain why there was great disparity in results from field and laboratory conditions—exposures in captive settings generally exceeded 170 dB before inducing behavioral responses. Below we summarize some of the relevant material reviewed by Southall et al. (2007).

LGL and Greeneridge (1986) and Finley et al. (1990) documented belugas and narwhals congregated near ice edges reacting to the approach and passage of ice-breaking ships. Beluga whales responded to oncoming vessels by (1) fleeing at speeds of up to 20 km/h from distances of 20 to 80 km, (2) abandoning normal pod structure, and (3) modifying vocal behavior and/or emitting alarm calls. Narwhals, in contrast, generally demonstrated a “freeze” response, lying motionless or swimming slowly away (as far as 37 km down the ice edge), huddling in groups, and ceasing sound production. There was some evidence of habituation and reduced avoidance 2 to 3 days after onset.

The 1982 season observations by LGL & Greeneridge (1986) involved a single passage of an icebreaker with both ice-based and aerial measurements on 28 June 1982. Four groups of narwhals (n = 9 to 10, 7, 7, and 6) responded when the ship was 6.4 km away (received levels of ~100 dB in the 150- to 1,150-Hz band). At a later point, observers sighted belugas moving away from the source at >20 km (received levels of ~90 dB in the 150- to 1,150-Hz band). The total number of animals observed fleeing was about 300, suggesting approximately 100 independent groups (of three individuals each). No whales were sighted the following day, but some were sighted on 30 June, with ship noise audible at spectrum levels of approximately 55 dB/Hz (up to 4 kHz).

Observations during 1983 (LGL & Greeneridge 1986) involved two ice-breaking ships with aerial survey and ice-based observations during seven sampling periods. Narwhals and belugas generally reacted at received levels ranging from 101 to 121 dB in the 20- to 1,000-Hz band and at a distance of up to 65 km. Large numbers (100s) of beluga whales moved out of the area at higher received levels. As noise levels from icebreaking operations diminished, a total of 45 narwhals returned to the area and engaged in diving and foraging behavior. During the final sampling period, following an 8-h quiet interval, no reactions were seen from 28 narwhals and 17 belugas (at received levels ranging up to 115 dB).

The final season (1984) reported in LGL & Greeneridge (1986) involved aerial surveys before, during, and after the passage of two ice-breaking ships. During operations, no belugas and few narwhals were observed in an area approximately 27 km ahead of the vessels, and all whales sighted over 20 to 80 km from the ships were swimming strongly away. Additional observations confirmed the spatial extent of avoidance reactions to this sound source in this context.

Awbrey & Stewart (1983) played back semi-submersible drillship sounds (source level: 163 dB) to belugas in Alaska. They reported avoidance reactions at 300 and 1,500 m and approach by groups at a distance of 3,500 m (received levels ~110 to 145 dB over these ranges assuming a 15 log R transmission loss). Similarly, Richardson et al. (1990) played back drilling platform sounds (source level: 163 dB) to belugas in Alaska. They conducted aerial observations of eight individuals among ~100 spread over an area several hundred meters to several kilometers from the sound source and found no obvious reactions. Moderate changes in movement were noted for three groups swimming within 200 m of the sound projector.

Finally, two recent papers deal with important issues related to changes in marine mammal vocal behavior as a function of variable background noise levels. Foote et al. (2004) found increases in the duration of killer whale calls over the period 1977 to 2003, during which time vessel traffic in Puget Sound, and particularly whale-watching boats around the animals, increased dramatically. Scheifele et al. (2005) demonstrated that belugas in the St. Lawrence River increased the levels of their vocalizations as a function of the background noise level (the “Lombard Effect”).

Several researchers conducting laboratory experiments on hearing and the effects of nonpulse sounds on hearing in mid-frequency cetaceans have reported concurrent behavioral responses. Nachtigall et al. (2003) reported that noise exposures up to 179 dB and 55-min duration affected the trained behaviors of a bottlenose dolphin participating in a TTS experiment. Finneran and Schlundt (2004) provided a detailed, comprehensive analysis of the behavioral responses of belugas and bottlenose dolphins to 1-s tones (received levels 160 to 202 dB) in the context of TTS experiments. Romano et al. (2004) investigated the physiological responses of a bottlenose dolphin and a beluga exposed to these tonal exposures and demonstrated a decrease in blood cortisol levels during a series of exposures between 130 and 201 dB. Collectively, the laboratory observations suggested the onset of behavioral response at higher received levels than did field studies. The differences were likely related to the very different conditions and contextual variables between untrained, free-ranging individuals vs. laboratory subjects that were rewarded with food for tolerating noise exposure.

Pinnipeds

Pinnipeds generally seem to be less responsive to exposure to industrial sound than most cetaceans. Pinniped responses to underwater sound from some types of industrial activities such as seismic exploration appear to be temporary and localized (Harris et al. 2001, Reiser et al. 2009b).

Blackwell et al. (2004) reported little or no reaction of ringed seals in response to pile-driving activities during construction of a man-made island in the Beaufort Sea. Ringed seals were observed swimming as close as 46 m from the island and may have been habituated to the sounds which were likely audible at distances <3000 m underwater and 0.5 km in air. Moulton et al. (2003) reported that ringed seal densities on ice in the vicinity of a man-made island in the Beaufort Sea did not change significantly before and after construction and drilling activities.

Southall et al. (2007) reviewed literature describing responses of pinnipeds to non-pulsed sound and reported that the limited data suggest exposures between ~90 and 140 dB generally do not appear to induce strong behavioral responses in pinnipeds exposed to nonpulse sounds in water; no data exist regarding exposures at higher levels. It is important to note that among these studies of pinnipeds responding to nonpulse exposures in water, there are some apparent differences in responses between field and laboratory conditions. In contrast to the mid-frequency odontocetes, captive pinnipeds responded more strongly at lower levels than did animals in the field. Again, contextual issues are the likely cause of this difference.

Jacobs & Terhune (2002) observed harbor seal reactions to AHDs (source level in this study was 172 dB) deployed around aquaculture sites. Seals were generally unresponsive to sounds from the AHDs. During two specific events, individuals came within 43 and 44 m of active AHDs and failed to demonstrate any measurable behavioral response; estimated received levels based on the measures given were ~120 to 130 dB.

Costa et al. (2003) measured received noise levels from an Acoustic Thermometry of Ocean Climate (ATOC) program sound source off northern California using acoustic data loggers placed on translocated elephant seals. Subjects were captured on land, transported to sea, instrumented with archival acoustic tags, and released such that their transit would lead them near an active ATOC source (at 939-m depth; 75-Hz signal with 37.5- Hz bandwidth; 195 dB max. source level, ramped up from 165 dB over 20 min) on their return to a haulout site. Received exposure levels of the ATOC source for experimental subjects averaged 128 dB (range 118 to 137) in the 60- to 90-Hz band. None of the instrumented animals terminated dives or radically altered behavior upon exposure, but some statistically significant changes in diving parameters were documented in nine individuals. Translocated northern elephant seals exposed to this particular nonpulse source began to demonstrate subtle behavioral changes at ~120 to 140 dB exposure RLs.

Kastelein et al. (2006) exposed nine captive harbor seals in a ~25 × 30 m enclosure to nonpulse sounds used in underwater data communication systems (similar to acoustic modems). Test signals were frequency modulated tones, sweeps, and bands of noise with fundamental frequencies between 8 and 16 kHz; 128 to 130 [± 3] dB source levels; 1- to 2-s duration [60-80% duty cycle]; or 100% duty cycle. They recorded seal positions and the mean number of individual surfacing behaviors during control periods (no exposure), before exposure, and in 15-min experimental sessions (n = 7 exposures for each sound type). Seals generally swam away from each source at received levels of ~107 dB, avoiding it by ~5 m, although they did not haul out of the water or change surfacing behavior. Seal reactions did not appear to wane over repeated exposure (i.e., there was no obvious habituation), and the colony of seals generally returned to baseline conditions following exposure. The seals were not reinforced with food for remaining in the sound field.

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.

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 activities. There is little or no bowhead hunting by the community of Point Lay, so beluga and walrus hunting are of greater importance there. Members of the Wainwright community hunt bowhead whales primarily in the spring, although the first recorded successful fall bowhead whale hunt occurred in 2010. 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 7). 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. 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 7). The spring hunts at Wainwright and Barrow occur after leads open due to the deterioration of pack ice; the spring hunt typically occurs from early April until the first week of June. The fall migration of bowhead whales that summer in the eastern Beaufort Sea typically begins in late August or September. Fall migration through Alaskan waters is primarily during September and October.

In the fall, subsistence hunters use aluminum or fiberglass boats with outboard motors. 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 the planned site survey and geotechnical soil investigations 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 dates for the activities in the Chukchi Sea (~25 July and ~1 August, respectively) are well after the end of the spring bowhead migration and hunt at Wainwright and Barrow. Site survey and soil investigation operations will be conducted far offshore from Barrow and Wainwright are not expected to conflict with fall subsistence hunting activities. Specific concerns of the Barrow and Wainwright 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).

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 into July or August. The community of Point Lay is heavily dependent on the hunting of belugas in Kasegaluk Lagoon for subsistence food. 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 8). The planned activities will take place well offshore, far away from areas that are used for beluga hunting by the Chukchi Sea communities.

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 8. Although ringed seals are available year-round, the planned activities will not occur during the primary period when these seals are typically harvested. Also, the activities will be largely in offshore waters where they 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 8). Spotted seals typically migrate south by October to overwinter in the Bering Sea. During the fall migration, spotted seals are hunted by the Wainwright 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 planned activities 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 Wainwright, 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 8). The animals inhabit the environment around 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 activities so no conflicts with the harvest of bearded seals are expected.

TABLE 7. 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	-

TABLE 8. 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)

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 reported that, from 2003 to 2007, the average annual harvest of the Southern Beaufort Sea polar bear stock in Alaska was 37 (Allen and Angliss 2010). That includes harvests at all coastal communities. It is not expected that the proposed activities 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 impacted by the planned activities in the Chukchi Sea. However, the operations will not be conducted close to shore where subsistence hunting takes place.

In the event that both marine mammals and hunters are near the areas of planned operations, the proposed project potentially could impact the availability of marine mammals for harvest in a small area immediately around the vessels, in the case of pinnipeds, and possibly in a larger area in the case of migrating bowheads. However, the majority of marine mammals are taken by hunters within ~21 mi (~33 km) of shore, and the survey activities will occur far offshore, well outside the hunting areas. Considering the timing and location of the proposed activities, as described in Sections 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).

Subsistence Fishing

Subsistence fishing is conducted throughout 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 activities are planned. Because of the close relationship between most subsistence fishing in the Chukchi Sea and the hunting activities described above, it is also expected that the proposed project will not have any significant impacts to subsistence fishing.

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 activity as part of the site surveys 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 airguns on marine fish and invertebrate species, the primary food sources of pinnipeds and belugas, is limited.

In water, acute injury and death of organisms exposed to seismic energy depends primarily on two features of the sound source: 1) the received peak pressure, and 2) the time required for the pressure to rise and decay (Hubbs and Rechnitzer 1952; Wardle et al. 2001). Generally, the higher the received pressure and the less time required for the pressure to rise and decay, the greater the chance of acute pathological effects. Considering the peak pressure and rise/decay time characteristics of seismic airgun arrays used today, the pathological zone for fish and invertebrates would be expected to be within a few meters of the seismic source (Buchanan et al. 2004). For the proposed survey, any injurious effects on fish would be limited to very short distances, 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 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 sound 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 geotechnical soil investigations are expected to have minimal impacts on benthic communities. The diameter of the cores to be collected will be either 2.1 or 2.8 in., depending on the substrate material being cored. Lubrication of the borehole bit will be accomplished with sea-water including, if necessary, bentonite (clay) and barite material. As a result of drilling the boreholes, some cuttings and drilling muds will enter the water column and be carried away by the current. A small amount of material may also be deposited in the immediate vicinity of each borehole location impacting benthic organisms and their habitat.

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 airgun activities will be temporarily elevated noise levels and the associated direct effects on marine mammals, as discussed above.

During the seismic surveys, 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.

Of the marine mammal species commonly found in the Chukchi Sea, gray whale, bearded seal, and Pacific Walrus, are known to frequently feed on benthic organisms. The amount of disturbance to the benthic zone is expected to be limited to a few square meters around each borehole location. This level of impact is probably less than many natural events, such as ice gouge, that effect the benthos in some locations in the Chukchi Sea. Overall, the impacts to benthic communities from the geotechnical soil investigations are not expected to result in significant or long-term loss of benthic feeding habitat.

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 airguns is the main source of potential impacts on marine mammal species by the proposed activities. The response of an individual animal or group of animals depends on various factors, but most responses are likely short term behavioral responses, and no lethal injuries are expected, even in the absence of the mitigation measures proposed below. Implementation of the mitigation measures as described below will reduce the potential impacts to marine mammals.

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

- identifying transit routes and timing to avoid other subsistence use areas and communicate with coastal communities before operating in or passing through these areas, and;
- limiting the size of the seismic sound source to minimize energy introduced into the marine environment;
- establishing precautionary safety radii based on previous measurements of a similar sound source in the area for implementation prior to completion of sound source measurements in 2011.

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. Additional details regarding the mitigation and monitoring planned during this project can be found in the Marine Mammal Monitoring and Mitigation Plan (4MP) submitted with this application. The 4MP will be operated and administered consistent with monitoring programs conducted during seismic and shallow hazards surveys in 2006–2010 or such alternative requirements as may be specified in the authorizations issued this project.

Safety and Disturbance Zones

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

Initial safety and disturbance radii for the sound levels produced by the planned airgun configurations have been estimated (Table 1). These radii will be used for mitigation purposes until results of direct measurements are available early during the exploration activities. The proposed surveys will use an airgun source composed of 4, 10-in^3 airguns (total discharge volume of 40 in^3) and a single 10 in^3 airgun. Underwater sound propagation from a similar 4×10-in^3 airgun cluster and single 10 in^3 was measured in 2009 (Reiser et al. 2010). Those measurements resulted in 90th percentile propagation loss equations of $RL = 218.0 - 17.5LogR - 0.00061R$ for the 4×10 in^3 airgun cluster and $RL = 204.4 - 16.0LogR - 0.00082R$ for the single 10 in^3 airgun (where RL = received level and R = range). The estimated distances for the proposed 2011 activities are based on a 25% increase over 2009 results (Table 1).

In addition to the site surveys, Statoil plans to use a dedicated vessel to conduct geotechnical soil investigations. Sounds produced by the vessel and borehole drilling equipment are not expected to be above 180 dB (rms). Therefore, mitigation related to acoustic impacts from these activities are not expected to be necessary.

An acoustics contractor will perform direct measurements of the received levels of underwater sound versus distance and direction from the airguns and soil investigation vessel using calibrated hydrophones. The acoustic data will be analyzed as quickly as reasonably practicable in the field and used to verify and adjust the safety distances. The field report will be made available to NMFS and the MMOs within 120 hrs of completing the measurements. The mitigation measures to be implemented for sightings within or near at the 190 and 180 dB sound levels will include power downs and shut downs as described below.

Speed and Course Alterations

If a marine mammal is detected outside the applicable 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 will be considered if this does not compromise operational safety. For marine seismic surveys using large streamer arrays, course alterations are not typically possible. However, for the smaller airgun array and streamer planned during the proposed site surveys, such changes may be possible. After any such speed and/or course alteration is begun, 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, including a power down or shut down of the airgun(s).

Ramp Ups, Power Downs and Shut Downs

Ramp up, power down, 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. These procedures are consistent with requirements in recent IHAs issued by NMFS for Arctic projects.

Ramp Up Procedures

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

NMFS normally requires that, once ramp up commences, the rate of ramp up be no more than 6 dB per 5 min period. A 6 dB increase in source level is approximately equal to the doubling of the number of active airguns. Full ramp ups (i.e., from a cold start after a shut down, when no airguns have been firing) will begin by firing a single airgun in the array. An additional airgun will be added after 5 minutes, and the final two airguns will be added after another 5 minutes. During the ramp up, the safety zone for the full 4-airgun cluster will be maintained. A ramp up procedure can be applied only in the following situations:

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

During turns or brief transits between seismic transects, one airgun will continue operating. The ramp-up procedure will still be followed when increasing the source levels from one airgun to the full 4-airgun cluster. However, keeping one airgun firing will avoid the prohibition of a cold start during darkness or other periods of poor visibility. Through use of this approach, seismic operations can resume upon entry to a new transect without the 30-minute watch period of the full safety radius required for a cold start. MMOs will be on duty whenever the airguns are firing during daylight, and during the 30-min periods prior to ramp-ups as well as during ramp-ups. Daylight will occur for 24 h/day until mid-August, so until that date MMOs will automatically be observing during the 30-minute period preceding a ramp up. Later in the season, MMOs will be called to duty at night to observe prior to and during any ramp ups. The seismic operator and MMOs will maintain records of the times when ramp-ups start, and when the airgun arrays reach full power.

Power Down Procedures

A power down for immediate mitigation purposes is the immediate reduction in the number of operating airguns such that the radii of the 190 dB (rms) and 180 dB (rms) zones are decreased to the extent that an observed marine mammal(s) are not in the applicable safety zone of the full array. Power downs are also used while the vessel turns from the end of one survey line to the start of the next. During a power down, one airgun (or some other number of airguns less than the full airgun array) continues firing. The continued operation of one airgun is intended to (a) alert marine mammals to the presence of the seismic vessel in the area, and (b) retain the option of initiating a ramp up to full operations under poor visibility conditions.

The array will be immediately powered down whenever a marine mammal is sighted approaching close to or within the applicable safety zone of the full array, but is outside the applicable safety zone of the single mitigation airgun. Likewise, if a mammal is already within the safety zone when first detected, the airguns will be powered down immediately. If a marine mammal is sighted within or about to enter the applicable safety zone of the single mitigation airgun, it too will be shut down (see following section).

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 of the full array, or

- has not been seen within the zone for 15 min in the case of pinnipeds or small odontocetes, or
- has not been seen within the zone for 30 min in the case of mysticetes or large odontocetes.

Shut Down Procedures

The operating airgun(s) will be shut down completely if a marine mammal approaches or enters the then-applicable safety radius and a power down is not practical or adequate to reduce exposure to less than 190 or 180 dB (rms), as appropriate. In most cases, this means the mitigation airgun will be shut down completely if a marine mammal approaches or enters the estimated safety radius around the single 10 in^3 airgun while it is operating during a power down. Airgun activity will not resume until the marine mammal has cleared the safety radius. The animal will be considered to have cleared the safety radius as described above under power down procedures.

A shut down of the borehole equipment may be requested by MMOs if an animal is sighted approaching the vessel close enough to potentially interact with and be harmed by the soil investigation operation.

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 duration of their activities in the Chukchi Sea. Prior to the 2010 seismic surveys, Statoil began the stakeholder engagement process in 2009 by meeting with 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 their proposed 2011 activities. The POC will summarize the actions Statoil will take to identify important subsistence activities, inform subsistence users of the proposed survey activities, and obtain feedback from subsistence users and other community members regarding how to promote cooperation between the community, subsistence activities, and the Statoil program.

As part of the plan to mitigate potential impacts to subsistence users, a communication center in Wainwright will be jointly funded by Statoil and other operators, and Statoil will routinely call the communication center according to the established protocol while in the Chukchi Sea. Depending on survey progress Statoil may need to perform a crew change and/or refueling, which would occur in the

Nome area. The crew change will not involve the use of helicopters. Statoil does have a contingency plan for a potential transfer of a small number of crew via ship-to-shore vessel at Wainwright. If this should become necessary, the Wainwright communications center will be contacted to determine the appropriate vessel route and timing to avoid potential conflict with subsistence users.

During the early phase of the POC process for the proposed project, Statoil met with the North Slope Borough Department of Wildlife Management (Dec 2010) and the AEWC (mini-convention in Barrow, Feb 2011). Statoil visited and held public meetings in the affected Chukchi Sea villages, including Pt. Hope, Pt. Lay, Wainwright, and Barrow during the week of 21 March, 2011.

Based upon comments received at those meetings, as well as through other communications, a draft POC document continues to be developed. Upon completion, the draft POC will be submitted to each of the community leaders Statoil visited during the March meetings as well as other interested community members. Statoil will also submit the draft POC to NMFS, USFWS, and BOEMRE.

A final POC that documents all consultations with community leaders, subsistence user groups, individual subsistence users, and community members will be submitted to NMFS, USFWS, and BOEMRE upon completion of the consultations.

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 plans to conduct marine mammal and acoustic monitoring during the proposed project in order to implement mitigation measures, to satisfy the anticipated monitoring requirements of the IHA (and USFWS LoA), and to meet any monitoring and communication 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 (4MP) submitted along with this application. Statoil understands that the monitoring plan will be subject to review by NMFS, 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.

The objectives of the vessel-based visual monitoring program are:

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

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 review. 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 site survey and geotechnical soil investigation 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 vessel-based marine mammal monitoring will provide:

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

Marine Mammal Observers

Vessel-based monitoring for marine mammals will be performed by trained MMOs throughout the period of survey activities to comply with expected provisions in the IHA and LOA that Statoil receives. The observers will monitor the occurrence and behavior of marine mammals near the survey vessels during all daylight periods during operation, and during most daylight periods when airgun operations are not occurring. MMO duties will include watching for and identifying marine mammals; recording their numbers, distances, and reactions to the survey operations; and documenting "take by harassment" as defined by NMFS.

Number of Observers

A sufficient number of MMOs will be required onboard the survey vessel to meet the following criteria:

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

MMO teams will consist of Inupiat observers and experienced field biologists. An experienced field crew leader will supervise the MMO team onboard the survey vessels. The total number of MMOs may decrease later in the season as the duration of daylight decreases assuming NMFS does not require continuous nighttime monitoring. Statoil currently plans to have 5 MMOs aboard the site survey vessel and 3 MMOs aboard the soil investigation vessel, with the potential of reducing the number of MMOs later in the season as daylight periods decrease in length.

Observer Qualifications and Training

Crew leaders and most other biologists serving as observers in 2011 will be individuals with experience as observers during recent seismic or shallow hazards monitoring projects in Alaska, the Canadian Beaufort, or other offshore areas in recent years.

Observers will complete a two or three-day training session on marine mammal monitoring, to be conducted shortly before the anticipated start of the 2011 open-water season. The training session(s) will be conducted by qualified marine mammalogists with extensive crew-leader experience during previous vessel-based seismic monitoring programs. A marine mammal observers' handbook, adapted for the specifics of the planned survey program will be reviewed as part of the training.

Primary objectives of the training include:

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

Monitoring Methodology

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

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

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

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

Monitoring At Night and In Poor Visibility

Night-vision equipment (Generation 3 binocular image intensifiers, or equivalent units) will be available for use when/if needed. Past experience with night-vision devices (NVDs) in the Beaufort and Chukchi seas and elsewhere has indicated that NVDs are not nearly as effective as visual observation during daylight hours (e.g., Harris et al. 1997, 1998; Moulton and Lawson 2002).

Specialized Field Equipment

Statoil will provide or arrange for the following specialized field equipment for use by MMOs aboard the survey vessel: reticle binoculars, 20×60 image-stabilized Zeiss Binoculars or Fujinon 25×150

"Big-eye" binoculars, GPS unit, laptop computer(s), night vision binoculars, digital still and possibly digital video cameras.

Acoustic Monitoring

Sound Source Measurements

As described above, previous measurements of airguns in the Chukchi Sea were used to estimate the distances at which received levels are likely to fall below 120, 160, 180, and 190 dB rms from the planned airgun sources. These modeled distances will be used as temporary safety radii until measurements of the airgun sound source are conducted. The measurements will be made at the beginning of the field season and the measured radii used for the remainder of the survey period. An acoustics contractor will use their equipment to record and analyze the underwater sounds and write the summary reports as described below.

The objectives of the sound source verification measurements planned for 2011 in the Chukchi Sea will be (1) to measure the distances at which broadband received levels reach 190, 180, 170, 160, and 120 dB re 1 μPa (rsm) for the airgun configurations that may be used during the survey activities. The configurations will include at least the full array (4×10 in^3) and the operation of a single 10 in^3 airgun that will be used during power downs or very shallow penetration surveys.

Regional Acoustic Array

Statoil, Shell, and CPAI are working on plans to once again jointly fund an extensive environmental studies program in the Chukchi Sea. The planned 2011 acoustic program will continue the acoustic monitoring programs carried out in 2006–2010. A similar number of acoustic recorders as deployed in past years will be distributed broadly across the Chukchi Sea lease area and nearshore environment. In past years, clusters of recorders designed to localize marine mammal calls originating within or nearby the clusters have been deployed on each of the companies prospects: Amundsen (Statoil), Burger (Shell), and Klondike (CPAI). This year, recorders from the clusters are planned to be relocated in a broader deployment on and around Hanna Shoal.

The recorders will be deployed in late July or mid-August and will be retrieved in early to mid-October, depending on ice conditions. Recorders will also be deployed to over-winter in 2011-2012. The recorders will be AMAR and AURAL model acoustic buoys set to record at 16 kHz sample rate. These are the same recorder models and same sample rates that have been used for this program from 2007–2010. The broad area arrays are designed to capture both general background soundscape data, industrial sounds and marine mammal call data across the lease area. From previous deployments of these recordings we have been able to gain insight into large-scale distributions of marine mammals, identification of marine mammal species present, movement and migration patterns, and general abundance data.

Reporting

Field Reports

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

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 shown in Table 1.

90-day Report

The results of the 2011 vessel-based monitoring, including estimates of "take by harassment", will be presented in 90-day and final technical reports. Reporting will address the requirements established by NMFS and USFWS.

The technical report(s) will include:

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

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 planned activities. In 2009 and 2010 Statoil participated in baseline scientific research efforts in the Chukchi Sea. The research conducted included, acoustics monitoring, fisheries ecology, benthic ecology, plankton ecology, marine mammal surveys, seabird surveys, and physical oceanography. This program is intended to provide scientific data on multiple aspects of the Chukchi Sea environment and help to inform planning and decision making in future years.

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: http://www.soundandmarinelife.org/.

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APPENDIX A:
DESCRIPTION OF VESSELS

M/V Duke – Shallow Hazards and Site Clearance Survey Vessel

M/V DUKE

Owner	Gardline CGGV Pte Ltd
Flag	Bahamas
Port Of Registry	Nassau
Built / Rebuilt	1983, A/S Vaagen Verft, Norway/1998
Class	DNV 1A1-E0-Sealer (for max. draught 5.30m) pwdk
Class ID N°	DNV 13520
IMO Number	8200838
Call Sign	LACS4
Length (overall)	66,8 m
Beam	13,00 m
Max Draft	5,80 m
Gross Tonnage	2031 GRT
Net Tonnage	610
Maximum Load Speed	12 kts
Cruising Speed	11,5 kts
Fuel Capacity	660 m3
Fuel Consumption	At 10.0-11.5 knots: 9m3 / 24h All 2D Seismic gear out (4,5 knots) appr. 11m3 / 24h Site Survey appr. 5.5m3 / 24h At Stand by (one engine running): appr. 4m3 / 24h
Endurance	50-60 days in survey mode
Range at Cruising Speed	12-13000 nm

Fresh Water	110 m3
Fresh Water Production	2 Alfa Laval, JWP C40. 8 m3/24 hrs total
Sewage	1 Sewage Treatment Plant Bioepuro – B/20 – EC Type Ex
Cable Oil Capacity	28m3
Roll Reduction Tanks	76m3
Water Ballast	2C 109m3, 3P 69m3, 3S 69m3. total 247m3
Provision Rooms	1 Freezer room ca.20m3. 1 Fhiller room ca. 18m3
Engines	2 MAK 6M 453aK 1640 kW / 2250 bhp each at 600 RPM
Total Propulsion	3280 KW
Propellers	1 Hjelset var.pitch. type HM 1530. Rpm 246. Dia 2800mm
Azimuth Thruster	NA
Bow Thrusters	Brunvoll, 578 hp
Stern Thrusters	Brunvoll, 578 hp
Generators	1 x E.C.C. 1640kVA shaft generator
Auxiliary Generator	2 x Stamford MC 534C - 305 kVA aux. generator
Electrical Distribution	1 x E.C.C. 1640kVA shaft generator 1 x Stamford MC 234C - 112,5kVA Harbour gen. 2 x Stamford MC 534C - 305 kVA aux. generator 440/220V 60Hz
Seismic Compressors	2 x Hamworthy 800E + 2 x Hamworthy 425E (scfm)
Safe Manning Certificate	50 persons

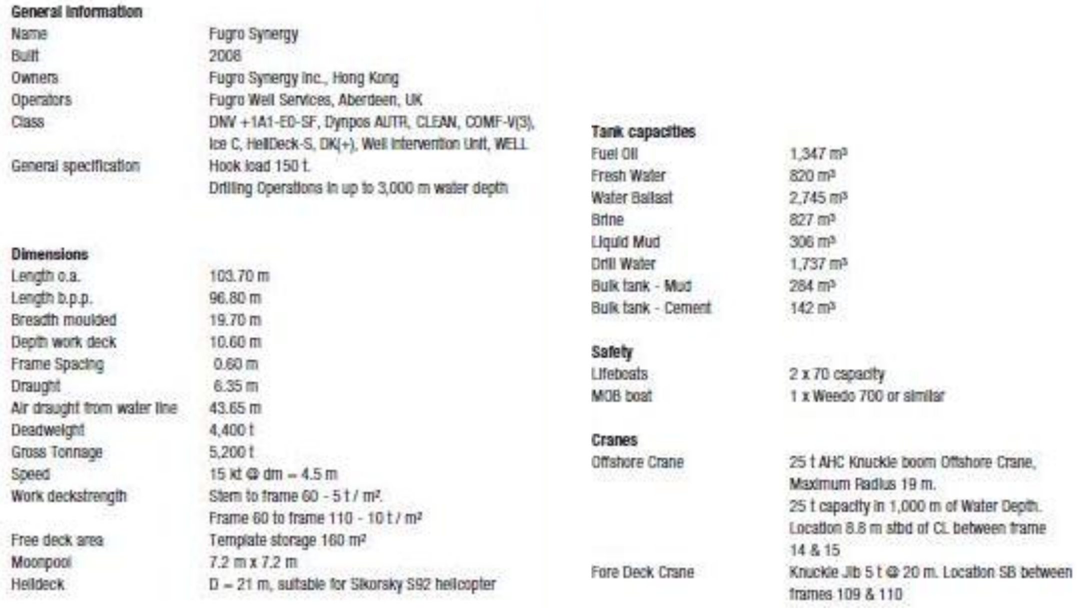
Communication Systems	
VHF Portable	1 Sailor RT 143 1 Sailor RT 144 3 Tron GMDSS Emergency.
MF/HF Radio	Sailor HC 4500 with DSC
INMARSAT B Receivers & Number	Nerasat B: 325 74 55 10 (Radio station)
INMARSAT C	2 x Sailor/Thrane & Trane TT-3020C. tlx nr. 425745510/11
VSAT Receivers & Number	Internet and 3 phone lines: Bridge: + 44 1493 888 127 / +8707 6487 6369 Party Chief: + 65 3 108 02 99 Inst.Room: + 61 8 6555 1633 Ships office: + TBC Fax: +8707 6487 6371
Marisat Receivers & Number	
Weather Facsimile	1 Furuno Fax 210
Navtex Receiver	1 Furuno NX-500
Data Transfer	FTP
Emergency Radio Beacon (Epirb)	2 x Tron 40S
Radar Transponder	2 x Tron Sart 9 ghz

Navigation Systems	
Radars	1 Furuno FAR 2837 Arpa , 10cm S-band 1 Furuno FR2115, Arpa, 3cm, X- band
Gyro Compass	2 Anschutz st. 20
Autopilot	1 Anschutz NP2010 Bacic Type AP01-S01

	1 Robertson AP9 MK3
Speed Log	1 Skipper EML224
Echo Sounder	1 Furuno Color Video Sounder FCV 1100
ECDIS	Admiral with C-Map
Robtrack	1 Roberson STS500 Robtrack
GPS	1 Furuno GP - 80 1 Furuno GP - 70
Magnetic Compass	2 Anschutz st. 20
Wind Indicator	1 Nautic system
AIS	Simrad A170
Voyage Recorder	1 Rutter Technologies VDR-100 G2S
SAFETY EQUIPMENT	
FRC/Mob boat	1 UFAS Weedo 17 Solas with 85 bhp outboard
Lifeboats	2 Waterman-Fiskars OY, 50 pers. Each
EPIRB	2 x Tron 40S
Life Rafts	4 x Viking, Type D.K. 20 persons each. 1x 6 persons.Type Zodiac for mob at the stern.
Survival Suits	30 FCO-OBAN MK90, Universal size. 5 FCO-OBAN MK90, XL size. 45 Fitzwright of Canada 7 Viking for Workboat & mob.
Life Vests	56
Work Vests	2 Helly Hansen, for Work-boat personnel. 4 Helly Hansen 9 Crewsaver
Life Buoys	9

Firefighting Equipment	
Engine Room	FM – 200
Compressor Room	Portable ABC powder and AFFF foam
Instrument Room	Portable
Gun Shack	Portable
Hazchem Storage	Portable
Galley	Portable
Accommodation	Portable
Tape Store	Portable
Streamer Area and Cable Repair Room	AFFF
Paint Store	AFFF
Incinerator	Portable ABC Powder
Main Foam Pump, Afff Foam Mixture	1 Fixed foam system for Top deck and streamer reel
Main Fire Pump Type/flow	2 x El. 50m3/h 60mLc, 9bar
Emergency Fire Pump Type/flow	1 x Motor driven 37m3/h 60mLc, 9 bar
Fire Detection Monitoring System	ANX-95
Fire Blankets	Galley
Top Streamer deck	2 x rotational fire monitors.

M/V Fugro Synergy – Geotechnical Soil Investigation Vessel



General information	
Name	Fugro Synergy
Built	2008
Owners	Fugro Synergy Inc., Hong Kong
Operators	Fugro Well Services, Aberdeen, UK
Class	DNV +1A1-E0-SF, Dynpos AUTR, CLEAN, COMF-V(3), Ice C, HeliDeck-S, DK(+), Well Intervention Unit, WELL
General specification	Hook load 150 t. Drilling Operations in up to 3,000 m water depth
Dimensions	
Length o.a.	103.70 m
Length b.p.p.	96.80 m
Breadth moulded	19.70 m
Depth work deck	10.60 m
Frame Spacing	0.60 m
Draught	6.35 m
Air draught from water line	43.65 m
Deadweight	4,400 t
Gross Tonnage	5,200 t
Speed	15 kt @ dm = 4.5 m
Work deckstrength	Stern to frame 60 - 5 t / m^2. Frame 60 to frame 110 - 10 t / m^2
Free deck area	Template storage 160 m^2
Moonpool	7.2 m x 7.2 m
Helideck	D = 21 m, suitable for Sikorsky S92 helicopter

Tank capacities	
Fuel Oil	1,347 m^3
Fresh Water	820 m^3
Water Ballast	2,745 m^3
Brine	827 m^3
Liquid Mud	306 m^3
Drill Water	1,737 m^3
Bulk tank - Mud	284 m^3
Bulk tank - Cement	142 m^3
Safety	
Lifeboats	2 x 70 capacity
MOB boat	1 x Weedo 700 or similar
Cranes	
Offshore Crane	25 t AHC Knuckle boom Offshore Crane, Maximum Radius 19 m. 25 t capacity in 1,000 m of Water Depth. Location 8.8 m stbd of CL between frame 14 & 15
Fore Deck Crane	Knuckle Jib 5 t @ 20 m. Location SB between frames 109 & 110

Appendix A: Vessel Specifications

Machinery	
Main Engines	5 x Caterpillar type 3516C - 2,188 kW @ 1,800 rpm.
Main Engines Generators	5 x Siemens - 2,188 kW @ 1,800 rpm
Emergency Generator Engine	1 x Diesel Engine 189 kW @ 1,800 rpm
Emergency Generator	1 x 219 kVA 690 V 60 Hz @ 1,800 rpm
Electrical System	690/450/230V-60 Hz
Propulsion	2 x Ulstein-Aquamaster Azimuth Thruster type AZP100/M-260 - 2,200 kW @ 1800 rpm
Side thrusters	2 x Kamewa Ulstein TT2200 SS DPN CP Tunnel Thruster - 1,050 kW @ 1,190 rpm
Azimuth Thruster	1 x Ulstein-Aquamaster Azimuth Thruster type UL 1201 - 883 kW @ 1,800 rpm
Anchoring & Mooring	
Anchors	2 x 4,050 kg Bower
Mooring	2 x Mooring Winches Fwd 2 x aft 10 t Capstans
Navigation	
GPS	1 x 12 channel DGPS Furuno GP-90
Autopilot	Anschütz Pilotstar D

Auto tracking	Furuno FCR 28375
Gyro Compass	Anschütz Standard 22
Bridge Fathometer	Furuno FE 700
VHF Fixed Radios	Sailor RT4822
VHF additional	
VHF hand held	
VHF Survival Sets	
HF Radios	
Satellite Phone	Furuno Felcom 15
Marisat Transceivers	
Anemometer	
Doppler Log	
Current Indicator	
Dynamic positioning	
Type	DP2 - Kongsberg SDP
Reference System	1 x DGPS, 2 x MRU-5, 1 x Fanbeam Mk4, 1 x HiPap 500 (to 4,000 m), 1x Taut Wire Mk 15 (500 m)
Facilities	
Berths	70
Mess	53

APPENDIX B:
REVIEW OF THE EFFECTS OF AIRGUN SOUNDS ON MARINE MAMMALS[1]

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.

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

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

2.1 Toothed Whales (Odontocetes)

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

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

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

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

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

2.2 Baleen Whales (Mysticetes)

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

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

2.3 Seals and Sea Lions (Pinnipeds)

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

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

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

2.4 Manatees and Dugong (Sirenians)

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

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

2.5 Sea Otter and Polar Bear

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

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

3. Characteristics of Airgun Sounds

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

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

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

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

Seismic sound pulses received at any given point will arrive via a direct path, indirect paths that include reflection from the sea surface and bottom, and often indirect paths including segments through the bottom sediments. Sounds propagating via indirect paths travel longer distances and often arrive later than sounds arriving via a direct path. (However, sound traveling in the bottom may travel faster than that in the water, and thus may, in some situations, arrive slightly earlier than the direct arrival despite traveling a greater distance.) These variations in travel time have the effect of lengthening the duration of the received pulse, or may cause two or more received pulses from a single emitted pulse. Near the source, the predominant part of a seismic pulse is ~10–20 ms in duration. In comparison, the pulse duration as received at long horizontal distances can be much greater. For example, for one airgun array operating in the Beaufort Sea, pulse duration was ~300 ms at a distance of 8 km, 500 ms at 20 km, and 850 ms at 73 km (Greene and Richardson 1988).

The rms level for a given pulse (when measured over the duration of that pulse) depends on the extent to which propagation effects have "stretched" the duration of the pulse by the time it reaches the

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

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

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

Humpback Whales.—Responses of humpback whales to seismic surveys have been studied during migration, on the summer feeding grounds, and on Angolan winter breeding grounds; there has also been discussion of effects on the Brazilian wintering grounds. McCauley et al. (1998, 2000a) studied the responses of migrating humpback whales off Western Australia to a full-scale seismic survey with a 16-

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

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

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

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

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

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

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

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

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

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

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

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

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

In addition, fin/sei whales were less likely to remain submerged during periods of seismic shooting (Stone 2003).

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

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

Discussion and Conclusions.—Baleen whales generally tend to avoid operating airguns, but avoidance radii are quite variable. Whales are often reported to show no overt reactions to airgun pulses at distances beyond a few kilometers, even though the airgun pulses remain well above ambient noise levels out to much longer distances. However, studies done since the late 1990s of migrating humpback and migrating bowhead whales show reactions, including avoidance, that sometimes extend to greater distances than documented earlier. Avoidance distances often exceed the distances at which boat-based observers can see whales, so observations from the source vessel can be biased. Observations over broader areas may be needed to determine the range of potential effects of some large-source seismic surveys where effects on cetaceans may extend to considerable distances (Richardson et al. 1999; Bain and Williams 2006; Moore and Angliss 2006). Longer-range observations, when required, can sometimes be obtained via systematic aerial surveys or aircraft-based observations of behavior (e.g., Richardson et al. 1986, 1999; Miller et al. 1999, 2005; Yazvenko et al. 2007a,b) or by use of observers on one or more support vessels operating in coordination with the seismic vessel (e.g., Smultea et al. 2004; Johnson et al. 2007). However, the presence of other vessels near the source vessel can, at least at times, reduce sightability of cetaceans from the source vessel (Beland et al. 2009), thus complicating interpretation of sighting data.

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

Studies of gray, bowhead, and humpback whales have determined that received levels of pulses in the 160–170 dB re 1 μPa_{rms} range seem to cause obvious avoidance behavior in a substantial fraction of

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

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

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

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

5.2 Toothed Whales

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

Williams 2006; Holst et al. 2006; Stone and Tasker 2006; Potter et al. 2007; Hauser et al. 2008; Holst and Smultea 2008; Weir 2008a; Barkaszi et al. 2009; Richardson et al. 2009).

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

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

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

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

Observers stationed on seismic vessels operating off the U.K. from 1997 to 2000 have provided data on the occurrence and behavior of various toothed whales exposed to seismic pulses (Stone 2003; Gordon et al. 2004; Stone and Tasker 2006). Dolphins of various species often showed more evidence of avoidance of operating airgun arrays than has been reported previously for small odontocetes. Sighting rates of white-sided dolphins, white-beaked dolphins, *Lagenorhynchus* spp., and all small odontocetes combined were significantly lower during periods when large-volume[4] airgun arrays were shooting. Except for the pilot whale and bottlenose dolphin, CPA distances for all of the small odontocete species

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

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

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

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

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

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

Reactions of toothed whales to a single airgun or other small airgun source are not well documented, but tend to be less substantial than reactions to large airgun arrays (e.g., Stone 2003; Stone and

Tasker 2006). During 91 site surveys off the U.K. in 1997–2000, sighting rates of all small odontocetes combined were significantly lower during periods the low-volume[5] airgun sources were operating, and effects on orientation were evident for all species and groups tested (Stone and Tasker 2006). Results from four NSF-funded L-DEO seismic surveys using small arrays (up to 3 GI guns and 315 in^3) were inconclusive. During surveys in the Eastern Tropical Pacific (Holst et al. 2005b) and in the Northwest Atlantic (Haley and Koski 2004), detection rates were slightly lower during seismic compared to non-seismic periods. However, mean CPAs were closer during seismic operations during one cruise (Holst et al. 2005b), and greater during the other cruise (Haley and Koski 2004). Interpretation of the data was confounded by the fact that survey effort and/or number of sightings during non-seismic periods during both surveys was small. Results from another two small-array surveys were even more variable (MacLean and Koski 2005; Smultea and Holst 2008).

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

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

Phocoenids (Porpoises).—Porpoises, like delphinids, show variable reactions to seismic operations, and reactions apparently depend on species. The limited available data suggest that harbor porpoises show stronger avoidance of seismic operations than Dall’s porpoises (Stone 2003; MacLean and Koski 2005; Bain and Williams 2006). In Washington State waters, the harbor porpoise—despite being considered a high-frequency specialist—appeared to be the species affected by the lowest received level of airgun sound (<145 dB re 1 μPa_{rms} at a distance >70 km; Bain and Williams 2006). Similarly,

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

during seismic surveys with large airgun arrays off the U.K. in 1997–2000, there were significant differences in directions of travel by harbor porpoises during periods when the airguns were shooting vs. silent (Stone 2003; Stone and Tasker 2006). A captive harbor porpoise exposed to single sound pulses from a small airgun showed aversive behavior upon receipt of a pulse with received level above 174 dB re 1 $\mu Pa_{pk\text{-}pk}$ or SEL >145 dB re 1 $\mu Pa^2 \cdot s$ (Lucke et al. 2009). In contrast, Dall's porpoises seem relatively tolerant of airgun operations (MacLean and Koski 2005; Bain and Williams 2006), although they too have been observed to avoid large arrays of operating airguns (Calambokidis and Osmek 1998; Bain and Williams 2006). The apparent tendency for greater responsiveness in the harbor porpoise is consistent with their relative responsiveness to boat traffic and some other acoustic sources (Richardson et al. 1995; Southall et al. 2007).

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

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

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

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

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

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

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

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

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

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

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

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

5.3 Pinnipeds

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

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

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

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

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

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

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

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

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

5.4 Sirenians, Sea Otter and Polar Bear

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

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

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

6. Hearing Impairment and Other Physical Effects of Seismic Surveys

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

- the 180-dB criterion for cetaceans is probably quite precautionary, i.e., lower than necessary to avoid temporary auditory impairment let alone permanent auditory injury, at least for delphinids.
- TTS is not injury and does not constitute “Level A harassment” in U.S. MMPA terminology.
- the minimum sound level necessary to cause permanent hearing impairment (“Level A harassment”) is higher, by a variable and generally unknown amount, than the level that induces barely-detectable TTS.
- the level associated with the onset of TTS is often considered to be a level below which there is no danger of permanent damage. The actual PTS threshold is likely to be well above the level causing onset of TTS (Southall et al. 2007).

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

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

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

6.1 Temporary Threshold Shift (TTS)

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

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

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

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

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

On the other hand, the TTS threshold for odontocetes exposed to a single impulse from a watergun (Finneran et al. 2002) appeared to be somewhat lower than for exposure to non-impulse sound. This was expected, based on evidence from terrestrial mammals showing that broadband pulsed sounds with rapid rise times have greater auditory effect than do non-impulse sounds (Southall et al. 2007). The received energy level of a single seismic pulse that caused the onset of mild TTS in the beluga, as measured without frequency weighting, was ~186 dB re 1 $\mu Pa^2 \cdot s$ or 186 dB SEL (Finneran et al. 2002).[6] The rms level of an airgun pulse (in dB re 1 μPa measured over the duration of the pulse) is typically 10–15 dB higher than the SEL for the same pulse when received within a few kilometers of the airguns. Thus, a single airgun pulse might need to have a received level of ~196–201 dB re 1 μPa_{rms} in order to produce brief, mild TTS. Exposure to several strong seismic pulses that each has a flat-weighted received level near 190 dB_{rms} (175–180 dB SEL) could result in cumulative exposure of ~186 dB SEL (flat-weighted) or ~183 dB SEL (M_{mf}-weighted), and thus slight TTS in a small odontocete. That assumes that the TTS threshold upon exposure to multiple pulses is (to a first approximation) a function of the total received pulse energy, without allowance for any recovery between pulses.

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

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

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

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

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

levels at those low frequencies tend to be higher. As a result, auditory thresholds of baleen whales within their frequency band of best hearing are believed to be higher (less sensitive) than are those of odontocetes at their best frequencies (Clark and Ellison 2004). From this, it is suspected that received levels causing TTS onset may also be higher in mysticetes (Southall et al. 2007). However, based on preliminary simulation modeling that attempted to allow for various uncertainties in assumptions and variability around population means, Gedamke et al. (2008) suggested that some baleen whales whose closest point of approach to a seismic vessel is 1 km or more could experience TTS or even PTS.

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

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

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

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

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

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

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

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

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

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

6.2 Permanent Threshold Shift (PTS)

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

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

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

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

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

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

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

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

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

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

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

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

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

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

6.3 Strandings and Mortality

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

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

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

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

6.4 Non-Auditory Physiological Effects

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

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

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