MARINE MAMMAL MONITORING AND MITIGATION DURING MARINE GEOPHYSICAL SURVEYS BY SHELL OFFSHORE INC. IN THE ALASKAN CHUKCHI AND BEAUFORT SEAS, JULY–OCTOBER 2010: 90-DAY REPORT

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~	approximately
AASM	Airgun Array Source Model
AEWC	Alaska Eskimo Whaling Commission
Bf	Beaufort Wind Force
BO	Biological Opinion
CAA	Conflict Avoidance Agreement
CFR	(U.S.) Code of Federal Regulations
CITES	Convention on International Trade in Endangered Species
cm	centimeter
CPA	Closest (Observed) Point of Approach
CTD	conductivity, temperature, depth
dB	decibel
EA	Environmental Assessment
EFD	Energy Flux Density
ESA	(U.S.) Endangered Species Act
f(0)	sighting probability density at zero perpendicular distance from survey track; equivalently, 1/(effective strip width)
ft	feet
FRC	Fast Rescue Craft
GI	Generator Injector
GIS	Geographic Information System
GMT	Greenwich Mean Time
GPS	Global Positioning System
g(0)	probability of seeing a group located directly on a survey line
h	hours
hp	horse power
Hz	Hertz (cycles per second)
IHA	Incidental Harassment Authorization (under U.S. MMPA)
in^3	cubic inches
IUCN	International Union for the Conservation of Nature
kHz	kilohertz
km	kilometer
km^2	square kilometers
km/h	kilometers per hour
kt	knots
LoA	Letter of Authorization
µPa	micro Pascal
m	meters
MBB	Multibeam Bathymetric (sonar)
MCS	Multi-Channel Seismic
min	minutes
MMO	Marine Mammal Observer

MMPA	(U.S.) Marine Mammal Protection Act
MONM	Marine Operations Noise Model
n	sample size
n.mi.	nautical miles
NMFS	(U.S.) National Marine Fisheries Service
No.	number
PD	Power down of the airgun array to one airgun (in this study, from an output of 3147 in^3 to 30 or 155 in^3)
PE	Parabolic Equation
pk-pk	peak-to-peak
RAM	Range-dependent Acoustic Model
re	in reference to
rms	root-mean-square: an average, in the present context over the duration of a sound pulse
s	seconds
SD	Shut Down of airguns not associated with mitigation
s.d.	standard deviation
SEL	Sound Exposure Level: a measure of energy content, in dB re 1 $\mu Pa^2 \cdot s$
SOI	Shell Offshore, Inc.
SPL	Sound Pressure Level; the SPL for a seismic pulse is equivalent to its rms level
SZ	Shut Down of all airguns because of a marine mammal sighting near or within the safety radius
TTS	Temporary Threshold Shift
UNEP	United Nations Environmental Programme

EXECUTIVE SUMMARY

Background and Introduction

Shell Offshore, Inc. (Shell) conducted several types of marine surveys in the Chukchi and Beaufort seas during the 2010 open-water period. These activities included shallow hazard and site clearance surveys and strudel scour surveys in the Beaufort Sea, and ice gouge surveys in both seas in support of potential future oil and gas exploration and development. The ice gouge surveys were conducted from the R/V *Ocean Pioneer* and the shallow hazard surveys were conducted from the R/V *Mt. Mitchell*. The *Ocean Pioneer* operated a suite of geophysical survey equipment, including an autonomous underwater vehicle (AUV), but did not operate airguns. The *Mt. Mitchell* towed a relatively small airgun array in addition to other geophysical survey equipment. The M/V *Arctic Seal* was used for logistical support and crew changes.

Marine seismic surveys emit sounds into the water at levels that could affect marine mammal behavior and distribution, or perhaps cause temporary or permanent reduction in hearing sensitivity. These effects could constitute "taking" under the provisions of the U.S. Marine Mammal Protection Act (MMPA) and the U.S. Endangered Species Act (ESA). The National Marine Fisheries Service (NMFS) and the U.S. Fish and Wildlife Service (USFWS) share jurisdiction over the marine mammal species that were likely to be encountered during the project.

Shell's marine geophysical surveys and other exploration activities in the Chukchi and Beaufort seas were conducted under the jurisdiction of Incidental Harassment Authorizations (IHAs) issued by NMFS and Letters of Authorization (LoAs) issued by the USFWS. The IHAs and LoAs included provisions to minimize the possibility that marine mammals might occur close to the seismic source and be exposed to levels of sound high enough to cause hearing damage or other injuries, and to reduce behavioral disturbances that might be considered as "take by harassment" under the MMPA.

A mitigation program was conducted to avoid or minimize potential effects of Shell's marine surveys on marine mammals and subsistence hunting, and to ensure that Shell was in compliance with the provisions of the IHAs and LoAs. This required that marine mammal observers (MMOs) onboard the *Mt. Mitchell* detect marine mammals within or about to enter the designated safety radii, and in such cases request an immediate power down (or shut down if necessary) of the airguns. It also required that MMOs aboard the *Ocean Pioneer* and *Arctic Seal* implement general mitigation measures as stipulated by the IHAs and LoAs for all vessel-related activities.

The primary objectives of the monitoring and mitigation program were to:

1. provide real-time sighting data needed to implement the mitigation requirements;
2. estimate the numbers of marine mammals potentially exposed to strong seismic pulses; and
3. determine the reactions (if any) of marine mammals potentially exposed to seismic sound impulses and other vessel activities.

This 90-day report describes the methods and results for the monitoring work specifically required to meet the above primary objectives.

Marine Geophysical Surveys Described

Three vessels were used by Shell to conduct exploratory activities in the Chukchi and Beaufort seas in 2010. One vessel, the R/V *Mt. Mitchell*, operated a small (40-in^3) airgun array to conduct shallow hazard and site clearance surveys in the Beaufort Sea. No airgun activity associated with Shell's activities occurred in the Chukchi Sea in 2010. The *Mt. Mitchell* also used several other low-energy sources for marine survey activity in the Beaufort and Chukchi seas. The R/V *Ocean Pioneer* operated a suite of low-energy geophysical equipment and an autonomous underwater vehicle (AUV) to conduct marine surveys in the Chukchi and Beaufort seas. The *Ocean Pioneer* also used a vibratory coring system to extract core samples in both seas. A third vessel, the M/V *Arctic Seal*, was responsible for re-supply and crew-change support.

Shell's marine surveys in the Beaufort Sea in 2010 were conducted on or near specific lease holdings in Harrison and Camden bays. Measurements of underwater sound propagation from the airgun array and other low-energy sources on the *Mt. Mitchell* were conducted by JASCO on 13–14 Aug and 13 Sep in Harrison Bay. Sound radii based on these measurements were used for implementation of mitigation by MMOs during airgun activities.

Persistent ice conditions in Harrison Bay frequently precluded survey activities. The *Mt. Mitchell* operated periodically in the Beaufort Sea when ice conditions permitted from 13 Aug to 9 Oct after which the *Mt. Mitchell* terminated activities in the Beaufort Sea. The *Mt. Mitchell's* airguns were operated along 1453 km (903 mi) of trackline in the Beaufort Sea in 2010.

JASCO conducted measurements of sound propagation from the *Ocean Pioneer's* sub-bottom profiler and mini-cone penetrometer on 19 and 20 Aug in Camden Bay. JASCO made similar measurements of underwater sounds produced by the *Ocean Pioneer* itself and the sub-bottom profiler in Harrison Bay on 27 Aug. The *Ocean Pioneer* conducted marine surveys using these low-energy sources in Camden and Harrison bays periodically from 18 Aug to 6 Oct and departed the Beaufort Sea on 7 Oct.

Most marine survey activity in the Chukchi Sea in 2010 was conducted from the *Ocean Pioneer*. The *Mt. Mitchell* assisted the *Ocean Pioneer* near the end of the 2010 field season. JASCO conducted measurements of underwater sound propagation from equipment on the *Ocean Pioneer* including a sub-bottom profiler and multibeam sonar, Vibracore coring system, and source equipment associated with the AUV during 6–8 Aug near the Burger prospect. Marine surveys were conducted from the *Ocean Pioneer* on or near Shell lease holdings in the Chukchi Sea from 4 through 16 Sep after which she returned to the Beaufort Sea. The *Mt. Mitchell* conducted ice gouge surveys in the Chukchi Sea from 10–12 Oct after which poor weather conditions precluded further survey activity.

Vessel–based marine mammal monitoring and mitigation was conducted from the source vessels *Mt. Mitchell* and *Ocean Pioneer*, and from the supply vessel *Arctic Seal* throughout the survey operations in the Beaufort and Chukchi seas. Shell also conducted aerial surveys in support of the *Mt. Mitchell's* airgun activities during shallow hazards surveys in the Beaufort Sea from 16 Jul to 10 Oct.

Underwater Sound Measurements

Shell conducted marine survey work offshore Alaska in 2010, including shallow hazards surveying in Harrison Bay, Beaufort Sea, and Geotechnical Development surveying near its Burger prospect in the Chukchi Sea and at Harrison and Camden Bays in the Beaufort Sea. Shell was required to monitor and report underwater sound levels from its offshore survey operations as stipulated in its Incidental Harassment Authorization permit from NMFS for this work. JASCO Applied Sciences carried out the sound monitoring studies on behalf of Shell in August and September 2010. Chapter 3 of this report provides detailed descriptions of the methods employed for the sound study and gives the results of the measurements performed. An overview of the experimental and analysis methods and a summary of the low frequency source results are given below.

Shell's 2010 IHA stipulated a requirement to measure underwater sound levels in vicinity of certain noise-generating sources. The measurements were to be analyzed to determine the distances at which broadband sound levels reached the level A (auditory injury) and level B (behavioral disturbance) take criterion thresholds. For the purposes of this authorization, the thresholds for impulsive sounds were

190 and 180 dB re 1 μPa (rms) for level A takes of pinnipeds and cetaceans respectively. The level B threshold was 160 dB re 1 μPa (rms). The IHA also required that the distances corresponding to sound levels between 190 and 120 dB re 1 μPa (rms) be reported in 10 dB steps. Shell's 2010 IHA included new measurement requirements for characterizing sonar sounds that were not present in previous years' IHAs. Specifically the 2010 IHA required the acoustic characterization of several of the sonar sources, including those operating above 180 kHz. The 180 kHz frequency is generally considered the upper frequency limit of the audibility for animals that are sensitive to high frequencies (belugas, narwhals and porpoises). NMFS interest in these higher frequency sonar was related to the possibility that sub-band energy below 180 kHz might be produced even though the primary operating frequency may be higher.

The shallow hazards program was performed from the survey vessel *R/V Mt Mitchell*. The sound sources characterized from this program included a 40 in^3 airgun array consisting of four 10 in^3 airguns that were fired simultaneously. A single 10 in^3 airgun was used as a mitigation source during turns and on line approaches to ensure marine mammals would maintain distance and avoid being exposed to higher-level sounds from the 40 in^3 array each time this system started. The shallow hazards program also employed a sub-bottom profiler and single beam, multibeam and side-scan sonar. All of the above sources and vessel self-noise from the *Mt Mitchell* were monitored in this study.

The Geotechnical Development program sound sources included a sub-bottom profiler, single beam, multibeam and side-scan sonar operated from the *R/V Ocean Pioneer* and a second set of these instruments operated from a Kongsberg HUGIN 1000 Autonomous Underwater Vehicle (AUV). This program also employed a vibracore system and a cone penetrometer system for geotechnical evaluation of the seabed. All of the above sources and vessel self-noise from *Ocean Pioneer* were characterized as part of the sound measurement study.

Two types of sound measurement equipment were used for this characterization study. Measurements of sounds below 24 kHz were made with seabed-deployed Ocean Bottom Hydrophone (OBH) systems from JASCO Applied Sciences, recording at 48 kHz. Higher frequency sources were monitored with a Reson TC4014 hydrophone deployed over the side of the research vessel. This hydrophone signal was digitized at 1 MHz using a National Instruments 6251 NI-USB system. All hydrophones were calibrated by Reson. The digital acquisition systems were calibrated by JASCO in the lab. In-field calibrations of the OBH systems were performed using GRAS 42AC pistonphone calibrators immediately before and after each measurement. The calibration results are included in this report.

Distances to sound level thresholds (maximum of fore and aft directions) from the low frequency sources of the Shallow Hazards program are given below in Table 1, and for the Geotechnical Development program in Table 2.

Table 1. Sound level threshold distances for low frequency sources from the Shallow Hazards Program, based on 90th percentile fits to measurement data.

Measurement Site	90% rms SPL (dB re 1 μPa)	190	180	170	160	120
Harrison Bay	40 in^3 airgun array range (m)	36	110	620	1700	7700
Harrison Bay	10 in^3 airgun range (m)	3	22	150	600	5000
Harrison Bay	GeoPulse sub-bottom profiler	7	9	12	15	2100
Harrison Bay	Mt. Mitchell vessel range (m)				41	1800

Table 2. Sound level threshold distances for low frequency sources from the Geotechnical Development program, based on 90th percentile fits to measurement data.

Measurement Site	90% rms SPL (dB re 1 µPa)	190	180	170	160	120
Burger	Vibracore range (m)			15	69	30000
Burger	Sub-bottom prof. AUV range (m)				3	240
Burger	Sub-bott. prof. towfish range (m)				31	320
Camden Bay	Sub-bott. prof. towfish range (m)				1	300
Harrison Bay	Sub-bott. prof. towfish range (m)	16	18	20	22	1000
Burger	Ocean Pioneer range (m)				3	1600
Camden Bay	Ocean Pioneer range (m)				2	1900
Harrison Bay	Ocean Pioneer range (m)				8	5400

The sonar analysis was more involved than that required for the low frequency sources. The IHA requested that the sonar sounds be characterized as a function of frequency and presented in spectral (1 Hz band) and 1/3-octave band formats. During analysis of these sources we noticed additional sounds that were not produced by the sonar. These were attributed to a Doppler velocity log on the AUV and a communication sonar also on the AUV. The sonar signals and additional AUV sources were analyzed. The detailed results are reported in Chapter 3.

Beaufort Sea Vessel-Based Marine Mammal Monitoring Results

In total, 88 sightings of 134 cetaceans, 565 sightings of 592 seals, two sightings of nine Pacific walruses, and seven sightings of nine polar bears were recorded during Shell's 2010 Beaufort Sea marine surveys. Bowhead whale was the only cetacean identified to species, and it is likely that many unidentified mysticete whales were also bowheads. Ringed seal was the most abundant seal species identified followed by bearded and spotted seals, respectively. Over half of the seals observed could not be identified to species. Both walrus sightings were recorded on 23 Aug from the *Mt. Mitchell*, and all of the animals were in water as opposed to on ice. All polar bears were initially detected on ice.

Cetacean sighting rates were higher in Sep–Oct than Jul–Aug, which was consistent with the timing of bowhead fall migration. No cetaceans were recorded during seismic periods. Seal sighting rates were similar between Jul–Aug and Sep–Oct and also between seismic and non-seismic periods. All Pacific walrus and polar bear sightings were recorded during non-seismic periods.

No cetaceans displayed any observable reaction to vessels. Most cetacean movements relative to vessels were "neutral" or "unknown." Cetaceans from 20% of sightings were recorded as "swimming away" from the vessel compared to 7% that were "swimming towards" the vessel.

The most frequently observed seal reaction to project vessels was to "look" at the vessel, followed by "splash." Seals "looked" at the vessel more frequently during seismic than non-seismic periods. Over 70% of seals however, demonstrated no detectable reaction to the vessel. The majority of seal movement relative to vessels was "neutral" or "unknown;" smaller numbers of seals "swam away" or "toward" vessels.

None of the Pacific walruses demonstrated a detectable reaction to vessels. No reaction to the vessel was recorded for four of the seven polar bear sightings. For the other three polar bear sightings, one "rushed" from ice into water and two "looked" at the vessel.

MMOs aboard the *Mt. Mitchell* were on watch during all airgun operations, including periods of darkness. Two power downs of the airgun array were requested and implemented on separate occasions due to seals approaching the ≥190 dB (rms) safety radius of the active array. No shut downs of the airgun array were necessary as a result of marine mammal sightings during the seismic survey. The first power down occurred on 1 Oct for a ringed seal and the second occurred on 10 Oct for a bearded seal. Neither of the animals entered the ≥190 dB (rms) safety radius of the full array or single mitigation gun, but mitigation was implemented as a precautionary measure. No power downs of the airguns were necessary for cetaceans, walruses, or polar bears during the 2010 survey.

In addition to seismic mitigation, numerous general mitigation measures were requested by MMOs and implemented on all three project vessels. These included reducing vessel speed for walrus sightings, altering course to avoid groups of marine mammals, maintaining a 805 m (0.5 mi) marine buffer from all walruses and polar bears (when practicable), and reducing vessel speed to below 10 kt during periods of poor visibility or when cetaceans were observed within or likely to come within 300 m (328 yd) of the vessel.

Based on direct observations, no cetaceans or walruses were exposed to received sound levels ≥180 dB (rms). Nor were any seals or polar bears observed in areas where received sound levels were ≥190 dB (rms).

Based on densities calculated from sighting rates during non-seismic periods, two individual cetaceans would have been exposed one time each to seismic sounds ≥180 dB (rms) if there was no avoidance of survey activities. Based on similar density calculations for seals, 13 individual seals would have been exposed once each to received levels ≥190 dB (rms) if these animals did not avoid the active airgun array. Non-seismic period densities for Pacific walruses and polar bears would have resulted in less than one of each animal being exposed to seismic sounds ≥180 and ≥190 dB (rms), respectively.

Beaufort Sea Aerial Survey Program Results

An aerial marine mammal monitoring program was conducted in the central Alaskan Beaufort Sea from 16 Jul to 9 Oct 2010 in support of Shell’s seismic exploration activities. Surveys were flown to obtain detailed data on the occurrence, distribution, and movements of marine mammals, particularly bowhead whales. Aerial surveys were also designed to monitor the ≥120 dB re 1 ųPa (rms) radius for cow/calf pairs with the intent of minimizing exposure of these groups to seismic sounds. If four or more cow/calf pairs were sighted within the ≥120 (rms) radius, the IHA required that seismic operations be shut down until less than four cow/calf pairs were observed on subsequent surveys. An additional requirement of the aerial monitoring program was to report any aggregations of 12 or more baleen whales within the ≥160 dB re 1 ųPa (rms) radius during seismic activities. Sightings that could potentially have required mitigation were communicated directly to MMOs on the *Mt. Mitchell*. However, no mitigation was required in 2010 as a result of observations made during aerial surveys.

In general, patterns of bowhead whale distribution, activity and headings in the Harrison Bay and Camden Bay survey areas in 2010 were similar to those reported in numerous previous studies, reflecting well–documented differences in seasonal use of the Alaskan Beaufort Sea by bowhead whales. Peak sighting rates occurred in late Aug (29 Aug) within Camden Bay and a few days later (8 Sep) in Harrison Bay. Whales in both areas were mostly observed heading west, which would be expected from fall migrants. Bowhead whales in Harrison Bay were observed predominately traveling while moving in a slow to moderate speed and tended to be dispersed between 15-70 km (9-43 mi) from shore. The peak sighting rate was recorded at 60-65 km (37-40 mi) offshore in waters around 10 m (33 ft) deep. Sightings made during Jul–Aug surveys of Camden Bay indicated that bowhead whales were primarily 15–35 km (9-22 mi) offshore in waters around 35 m (115 ft) deep.

Overall trends in beluga whale activity, speed, distance from shore, and sighting rates were also consistent with previous studies. Beluga sighting rates were highest in early Jul and the majority of migrating belugas appeared to pass north of our survey area, with peak sighting rates near the shelf break. Beluga activities consisted primarily of traveling at slow to moderate speeds. These data are consistent with prior research indicating that belugas spend the majority of their time in the Beaufort Sea along the shelf break or far offshore during spring and fall migrations.

Polar bear distribution was more dispersed than in previous years in the Harrison Bay area, which was likely related to persistent ice in the project area in 2010. In past years (2007 and 2008) most polar bear sightings were on barrier islands, but in 2010 all sightings were recorded on ice or in water.

Bowhead sighting rates during seismic and non-seismic periods were difficult to compare because seismic activity was not uniform through time, but rather had a distinctive peak at the end of the season. Because there was relatively little seismic effort earlier in the season, all of the bowhead sightings during seismic activity occurred during the last week of the aerial survey season. Furthermore, the peak in seismic activity occurred as the ice in Harrison Bay (which had persisted through the summer and early fall and stymied seismic survey effort early in the season), began to shift out of the study area. As a result of the relationship between seismic effort and ice conditions, bowhead sightings during seismic and non-seismic states generally occurred in two periods of different ice conditions in Harrison Bay.

Bowhead sightings were closer to the center of the survey area during seismic activity than when airguns were not active. This pattern may have resulted from changes in the distribution of ice in Harrison Bay. Hence, it appears that ice conditions (or other factors, perhaps related to the nature of the fall migratory path) may have had a greater effect on the distribution of bowheads than did seismic survey activity in 2010. The effect of seismic activity on bowhead distribution in the study area was somewhat confounded by the nature and timing of sightings, seismic activity and ice conditions, however, the number of bowheads exposed to underwater sound from seismic survey activities in 2010 appears to have been small. The estimate of 27 whales exposed to underwater sound≥160 dB in the Harrison Bay area represents a fraction equal to 0.0019 of the estimated population size in 2001.

Chukchi Sea Vessel-based Marine Mammal Monitoring Results

In total, 64 sightings of 101 cetaceans, 79 sightings of 86 seals, and 44 sightings of 131 Pacific walruses were recorded during Shell's 2010 Chukchi Sea marine surveys. No polar bears were observed in the Chukchi Sea during Shell's vessel operations in 2010. The most commonly identified cetacean was gray whale, followed by bowhead whale and harbor porpoise, respectively. Bearded seal was the most abundant seal species identified followed by spotted and ringed seals, respectively. Approximately 40% of the seals observed could not be identified to species.

Cetacean sighting rates were significantly higher in Sep–Oct than Jul–Aug ($\chi^2 = 4.04$, $df = 1$, $p = 0.044$).. Seal sighting rates were higher in Sep–Oct than Jul–Aug and Pacific walrus sighting rates were higher in Jul–Aug than Sep–Oct, but the differences were not significant in either case.

Cetaceans from 97% of sightings demonstrated no detectable reaction to project vessels; "change direction" was recorded for two of the 64 cetacean sightings. Most cetacean movements relative to vessels were "neutral" or "unknown." "Swimming away" from vessels was recorded for 20% of cetacean sightings compared to 11% for "swimming towards."

The most frequently observed seal reaction to survey vessels was to "look" at the vessel, followed by "increase speed" of travel. Over 65% of seals, however, demonstrated no detectable reaction to the vessel. The majority of seal movement relative to vessels was neutral or unknown; smaller numbers of seals swam away or toward vessels.

Over 90% of Pacific walruses demonstrated no detectable reaction to vessels in the Chukchi Sea during 2010. "Look" at the vessel was recorded for three of the 27 walrus sightings, and no other reactions were observed by MMOs. Approximately half of the walruses displayed "neutral" or no movement relative to the vessel with smaller percentages "swimming away" or "toward" the vessel.

Shell did not conduct seismic surveys in the Chukchi Sea in 2010, however, numerous general mitigation measures were requested by MMOs aboard all project vessels. These included reducing vessel speed for walrus sightings, altering course to avoid groups of marine mammals, maintaining a 805 m (0.5 mi) marine buffer from all walruses and polar bears (when practicable), reducing vessel speed to below 10 kt during periods of poor visibility or when cetaceans were observed within or likely to come within 300 m (328 yd) of the vessel, and transiting outside the polynya zone whenever survey activities were not being conducted.

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We thank the captains and crews of the R/V *Mt. Mitchell*, R/V *Ocean Pioneer*, and M/V *Arctic Seal* for their support during this project. Additionally, we appreciate the help of Deanne Hargrave and her team at Fugro Geo Services LLC. We also thank representatives of the National Marine Fisheries Service, U.S. Fish & Wildlife Service, North Slope Borough Department of Wildlife Management, Alaska Eskimo Whaling Commission, and Bureau of Ocean Energy Management, Regulation and Enforcement for their advice and comments during the "open-water meetings." Michael Macrander, Carol Theilen, Corey Allen, Matt Mercier, Christopher Leaf, Ben Vandorn, Jeremy Dean, Jonathan Smith, Susan Childs, Pete Slaiby, John Maketa, Kemal Xavier Bouraoui-Karoui, Dan Tesar, Aaron Merritt, Rebecca Mosquera, Leslie Smith, Michael Sotak, Paul Ramert, Alan Growden, Meghan Larson, Stacey Aughe, and Michelle Malerich provided valuable support prior to and during the field season. We also thank all of the MMOs who participated in the project. They were essential to the completion and success of this endeavor:

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1. BACKGROUND AND INTRODUCTION[1]

Shell Offshore, Inc. (Shell) conducted several types of marine surveys in the Chukchi and Beaufort seas during the 2010 open-water period. These activities included shallow hazard and site clearance surveys and strudel scour surveys in the Beaufort Sea, and ice gouge surveys in both seas in support of potential future oil and gas exploration and development. The ice gouge surveys were conducted from the R/V *Ocean Pioneer* and the shallow hazard surveys were conducted from the R/V *Mt. Mitchell*. The *Ocean Pioneer* operated a suite of geophysical survey equipment, including an autonomous underwater vehicle (AUV), but did not operate airguns. The *Mt. Mitchell* towed a relatively small airgun array in addition to other geophysical survey equipment. The M/V *Arctic Seal* was used for logistical support and crew changes.

Marine seismic surveys emit sound energy into the water (Greene and Richardson 1988; Tolstoy et al. 2004a,b) and have the potential to affect marine mammals given the reported auditory and behavioral sensitivity of many such species to underwater sounds (Richardson et al. 1995; Gordon et al. 2004). The effects could consist of behavioral or distributional changes, and perhaps (for animals close to the sound source) temporary or permanent reduction in hearing sensitivity. Either behavioral/distributional effects or auditory effects (if they occur) could constitute "taking" under the provisions of the U.S. Marine Mammal Protection Act (MMPA) and the U.S. Endangered Species Act (ESA), at least if the effects are considered to be "biologically significant."

Numerous species of cetaceans and pinnipeds inhabit parts of the Chukchi and Beaufort seas. The National Marine Fisheries Service (NMFS) and the U.S. Fish and Wildlife Service (USFWS) share jurisdiction over the marine mammal species that could be encountered during the project. Three species under NMFS jurisdiction that are listed as "Endangered" under the ESA, including bowhead whale (*Balaena mysticetus*), humpback whale (*Megaptera novaeangliae*), and fin whale (*Balaenoptera physalus*), do or may occur in portions of the survey areas. Additionally, NMFS initiated a status review to determine if listing as endangered or threatened under the ESA was warranted for four other species that occur in the project area including ringed seal (*Phoca fasciata*), spotted seal (*P. largha*), bearded seal (*Erignathus barbatus*), and ribbon seal (*Histriophoca fasciata*; NMFS 2008a,b). Subsequently the NMFS (2008c) announced that listing of the ribbon seal as threatened or endangered was not warranted at this time. More recently NMFS (2009) determined that no listing action was warranted for the Bering Sea and Okhotsk populations of spotted seal. NMFS (2009) however proposed a rule to list the southern spotted seal population in the Yellow Sea and Sea of Japan as threatened under the ESA. Most recently NMFS (2010a,b) issued proposed rules to list four subspecies of ringed seal (Arctic, Okhotsk, Baltic, and Ladoga) and two distinct population segments of bearded seal (Bering Sea and Okhotsk) as threatened under the ESA. These most recent proposed listings for ringed and bearded seals are open for public comment through 8 Feb 2011. The USFWS manages two marine mammal species occurring in the Chukchi and Beaufort seas, the Pacific walrus (*Odobenus rosmarus*) and polar bear (*Ursus maritimus*). The polar bear was recently listed as threatened under the ESA (USFWS 2008) and a petition to list Pacific walrus as threatened or endangered (CBD 2008) is under consideration by USFWS.

NMFS issued an Incidental Harassment Authorization (IHA) to Shell in 2009 to authorize non–lethal "takes" of marine mammals incidental to Shell's planned survey operations in the Chukchi Sea during the 2009 open–water season that was valid through 18 Aug 2010. (Appendix A). Pursuant to Section 101(a)(5)(D) of the MMPA, Shell requested that NMFS issue a similar IHA for the 2010 open–

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water season (Shell 2010). A notice announcing Shell's request for an IHA was published in the *Federal Register* on 18 May 2010 and public comments were invited (NMFS 2008b). A new IHA allowing marine surveys in the Chukchi and Beaufort seas was issued to Shell by NMFS on 6 Aug 2010 (Appendix A). The IHA authorized "potential take by harassment" of various cetacean and seal species during the marine geophysical cruises described in this report. This authorization was valid from 6 Aug 2010 through 30 Nov 2010.

On 9 Feb 2010, Shell requested a Letter of Authorization (LoA) from the USFWS for the incidental "take" of polar bears and Pacific walruses in relation to Shell's proposed open–water exploration program in the Beaufort and Chukchi seas in 2010. The USFWS issued two LoAs to Shell to "take" small numbers of polar bears and Pacific walruses incidental to activities occurring during the 2010 Beaufort and Chukchi sea marine survey programs, respectively. The LoAs were issued on 19 May 2010 and were valid to 30 Nov 2010 (Appendix B).

This document serves to meet reporting requirements specified in the IHA and LoAs. The primary purposes of this report are to describe project activities in the Chukchi and Beaufort seas, to describe the associated marine mammal monitoring and mitigation programs and their results, and to estimate the numbers of marine mammals potentially exposed to levels of sound generated by the seismic survey activities at or above presumed effect levels.

Incidental Harassment Authorization

IHAs issued to marine survey operators include provisions to minimize the possibility that marine mammals close to a seismic source might be exposed to levels of sound high enough to cause short or long–term hearing loss or other physiological injury. During this project, sounds were generated by a small airgun array on the *Mt. Mitchell*. The *Mt. Mitchell* and *Ocean Pioneer* also operated several types of lower–energy sound sources that included bottom mapping and seafloor imaging sonars, sub–bottom profilers, chirp sonars, and bubble pulsers. Given the nature of the operations and mitigation measures, no serious injuries or deaths of marine mammals were anticipated from the development and shallow hazards surveys. No such injuries or deaths were attributed to these activities. Nonetheless, the seismic survey operations described in Chapter 2 had the potential to "take" marine mammals by harassment. Behavioral disturbance to marine mammals is considered to be "take by harassment" under the provisions of the MMPA.

Under current NMFS guidelines (e.g., NMFS 2008b), "safety radii" for marine mammals around airgun arrays are customarily defined as the distances within which received pulsed sound levels are ≥180 dB re 1 μPa (rms)[2] for cetaceans and ≥190 dB re 1 μPa (rms) for pinnipeds. Those safety radii are based on

[2] "rms" means "root mean square", and represents a form of average across the duration of the sound pulse as received by the animal. Received levels of airgun pulses measured on an "rms" basis (sometimes described as Sound Pressure Level, SPL) are generally 10–12 dB lower than those measured on the "zero–to–peak" basis, and 16–18 dB lower than those measured on a "peak–to–peak" basis (Greene 1997; McCauley et al. 1998, 2000a,b). The latter two measures are the ones commonly used by geophysicists. Unless otherwise noted, all airgun pulse levels quoted in this report are rms levels. Received levels of pulsed sounds can also be described on an energy or "Sound Exposure Level" basis, for which the units are dB re $(1\ \mu Pa)^2 \cdot s$. The SEL value for a given airgun pulse, in those units, is typically 10–15 dB less than the rms level for the same pulse (Greene 1997; McCauley et al. 1998, 2000a,b), with considerable variability (Madsen et al. 2006; see also Chapter 3 of this report). SEL (energy) measures may be more relevant to marine mammals than are rms values (Southall et al. 2008), but the current regulatory requirements are based on rms values.

an assumption that seismic pulses at lower received levels will not injure these mammals or impair their hearing abilities, but that higher received levels *might* have some such effects. The mitigation measures required by IHAs are, in large part, designed to avoid or minimize the numbers of cetaceans and pinnipeds exposed to sound levels exceeding 180 and 190 dB (rms), respectively.

Disturbance to marine mammals could occur at distances beyond safety (shut down) radii if the mammals were exposed to moderately strong pulsed sounds generated by airguns or perhaps by sonar (Richardson et al. 1995). NMFS assumes that marine mammals exposed to airgun sounds with received levels ≥160 dB re 1 μPa (rms) are likely to be disturbed. That assumption is based mainly on data concerning behavioral responses of baleen whales, as summarized by Richardson et al. (1995) and Gordon et al. (2004). Dolphins and pinnipeds are generally less responsive than baleen whales (e.g., Stone 2003; Gordon et al. 2004), and 170 dB (rms) may be a more appropriate criterion of potential behavioral disturbance for those groups (LGL Ltd. 2005a,b).

In general, disturbance effects are expected to depend on the species of marine mammal, the activity of the animal at the time of disturbance, distance from the sound source, the received level of the sound and the associated water depth. Some individuals may exhibit behavioral responses at received levels somewhat below the nominal 160 or 170 dB (rms) criteria, but others may tolerate levels somewhat above 160 or 170 dB (rms) without reacting in any substantial manner. For example, migrating bowhead whales in the Alaskan Beaufort Sea have shown avoidance at received levels substantially lower than 160 dB re 1 μPa (rms; Miller et al. 1999; Richardson et al. 1999). Beluga whales may, at times, also show avoidance at received levels below 160 dB (rms; Miller et al. 2005). However, recently acquired acoustic evidence suggests that some whales may not react as much or in the same manner as suggested by those earlier studies. Blackwell et al. (2010) reported bowhead whale call detection rates were consistent across areas where received sound levels were ≤160 dB (rms), but call detections were unusual in areas where received sound levels were ≥180 dB (rms). Bowhead whales on the summer feeding grounds in the Canadian Beaufort Sea tolerate received levels of 160 dB (rms) or sometimes more without showing significant avoidance behavior (Richardson et al. 1986; Miller et al. 2005). Lyons et al. (2008) and Christie et al. (2010) reported bowhead whales tolerated received sound levels up to 160 dB (rms) in stopover feeding areas of the Alaskan Beaufort Sea during the fall migration period.

The IHA issued by NMFS to Shell authorized incidental harassment “takes” of two ESA–listed species including bowhead and humpback whales, as well as several non–listed species including gray whale (*Eschrichtius robustus*), beluga whale (*Delphinapterus leucas*), harbor porpoise (*Phocoena phocoena*), and ringed, spotted, and bearded seals.

NMFS granted the IHA to Shell on the assumptions that

- the numbers of whales and seals potentially harassed (as defined by NMFS criteria) during seismic operations would be “small”,
- the effects of such harassment on marine mammal populations would be negligible,
- no marine mammals would be seriously injured or killed,
- there would be no unmitigated adverse effects on the availability of marine mammals for subsistence hunting in Alaska, and
- the agreed upon monitoring and mitigation measures would be implemented.

The LoAs issued to Shell by USFWS required Shell to observe a 190 dB (rms) safety radius for polar bears and a 180 dB (rms) safety radius for walruses. These safety radii are consistent with those stipulated in prior LoAs dating back to 2007.

Mitigation and Monitoring Objectives

The objectives of the mitigation and monitoring program were described in detail in Shell's IHA application (Shell 2010) and in the 2010 IHA issued by NMFS to Shell (Appendix A). Explanatory material about the monitoring and mitigation requirements was published by NMFS in the *Federal Register* (NMFS 2008b).

The primary objectives of the monitoring program were to

- provide real–time sighting data needed to implement the mitigation requirements;
- estimate the numbers of marine mammals potentially exposed to strong seismic pulses; and
- determine the reactions (if any) of marine mammals potentially exposed to seismic sound impulses.

Specific mitigation and monitoring objectives and requirements identified in the IHA and LoAs are described in Appendices A and B. Mitigation and monitoring measures that were implemented during the activities in the Chukchi and Beaufort seas are described in detail in Chapter 4.

The purpose of the mitigation program was to avoid or minimize potential effects of Shell's marine surveys on marine mammals and subsistence hunting. For seismic surveys, this required that onboard marine mammal observers (MMOs) detect marine mammals within or about to enter the designated safety radii [190 dB (rms) for pinnipeds and polar bears, and 180 dB (rms) for cetaceans and walruses], and in such cases initiate an immediate power down (or shut down if necessary) of the airguns. A power down reduced the source level of the operating airguns, by reducing the number of airguns firing to a single gun. A shut down temporarily terminated the operation of all airguns. The safety radii were monitored in good visibility conditions for 30 minutes prior to starting the first airgun and during the ramp up procedure, which gradually increases the number of airguns firing, to ensure that marine mammals were not near the airguns when operations began (see Appendix A and Chapter 4). Numerous general mitigation measures were implemented by all survey vessels to maximize the distance between vessels and marine mammals and also to avoid separating groups of marine mammals. Furthermore, the location and timing of survey activities was planned in coordination with representatives of the North Slope communities avoid adverse impacts to subsistence harvests of marine mammals and other resources.

Mitigation at the 160 dB (rms) isopleth was also required in 2010, as specified in the IHA issued by NMFS, for an aggregation of 12 or more non–migratory mysticete whales. This area was monitored by onboard MMOs and by aerial surveys. Power down of the seismic airgun array was required if an aggregation of 12 or more non–migratory mysticete whales was detected ahead of, or perpendicular to, the seismic vessel track and within the 160 dB (rms) isopleth. Aerial monitoring of the 120 dB (rms) isopleth around the *Mt. Mitchell* was also required after 25 Aug in the Beaufort Sea. A power down was required if four or more bowhead whale cow/calf pairs were detected within the 120 dB (rms) isopleth.

Report Organization

This 90–day report describes the methods and results for the mitigation and monitoring work specifically required to meet the above objectives as required by the IHA and LoAs (Appendices A and B). Various other marine mammal and acoustic monitoring and research programs not specifically related to the above objectives were also implemented by Shell in the Chukchi and Beaufort seas during 2010. Results of those additional efforts will be reported at a later date.

This report includes seven chapters:

1. background and introduction (this chapter);

2. description of Shell's marine surveys;
3. results of acoustic sound source measurements during the field season;
4. description of the marine mammal monitoring and mitigation program (including seismic safety radii) and the vessel-based data analysis methods;
5. results of the vessel-based marine mammal monitoring program in the Beaufort Sea;
6. results of the aerial monitoring program in the Beaufort Sea.
7. results of the vessel-based marine mammal monitoring program in the Chukchi Sea;

In addition, 12 appendices provide copies of relevant documents and details of procedures that are more–or–less consistent during marine surveys where marine mammal monitoring and mitigation measures are in place. These procedural details are only summarized in the main body of this report. The appendices include:

A. copies of the IHAs issued by NMFS in 2009 and 2010 to Shell;
B. copies of the Chukchi and Beaufort sea LoAs issued by USFWS to Shell for 2010;
C. a copy of the Conflict Avoidance Agreement between Shell, the Alaska Eskimo Whaling Commission, and the Whaling Captains Associations;
D. descriptions of vessels and survey equipment;
E. details of vessel-based monitoring, mitigation, and data analysis methods;
F. Beaufort wind force definitions;
G. background on marine mammals in the Chukchi and Beaufort seas;
H. acoustic monitoring results (including English units tables and figures from Chapter 3);
I. English units tables and figures from Chapter 4;
J. vessel-based marine mammal monitoring results during the Beaufort Sea marine surveys (including all-sightings table and maps, English units tables and figures from Chapter 5);
K. marine mammal monitoring results during aerial surveys of the Beaufort Sea (including survey maps, English units tables and figures from Chapter 6);
L. vessel-based marine mammal monitoring results during the Chukchi Sea marine surveys (including all-sightings table and maps, English units tables and figures from Chapter 7).

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2. MARINE GEOPHYSICAL SURVEYS DESCRIBED[1]

Marine mammal monitoring was conducted from three vessels operated by Shell Offshore Inc. (Shell) in the Beaufort and Chukchi seas in 2010 in support of marine geophysical surveys. One vessel, the R/V *Mt. Mitchell*, operated a small airgun array to conduct shallow hazard and site clearance surveys in the Beaufort Sea. No airgun activity occurred in the Chukchi Sea in 2010. The *Mt. Mitchell* also used several other low-energy sources for marine survey activity in the Beaufort and Chukchi seas. The R/V *Ocean Pioneer* operated a suite of low-energy geophysical equipment and an autonomous underwater vehicle (AUV) to conduct marine surveys in the Chukchi and Beaufort seas. The *Ocean Pioneer* also used a vibratory coring system to extract core samples in both seas. Marine mammal observers (MMOs) were onboard these vessels to collect data on abundance and distribution of marine mammals in the vicinity of Shell's marine surveys and to request mitigation measures if necessary during survey activities. A single MMO was also onboard the supply vessel M/V *Arctic Seal* to record marine mammal observations during re-supply and crew change activities. The marine surveys and marine mammal monitoring are described below for the Beaufort Sea followed by a section describing similar activities in the Chukchi Sea.

Beaufort Sea Marine Surveys

As was the case in 2009, Shell did not conduct deep seismic exploration in the Chukchi or Beaufort seas in 2010. A relatively small airgun array on the *Mt. Mitchell* was used, however, during shallow hazards and site clearance surveys in the Beaufort Sea. Before drilling can begin, a site clearance survey and analysis is necessary to identify and/or evaluate potentially hazardous or otherwise sensitive conditions and sites at or below the seafloor that could affect the safety or appropriateness of operations. Examples of such conditions include subsurface faults, fault scarps, shallow gas, steep-walled canyons and slopes, buried channels, current scour, migrating sedimentary bedforms, ice gouging, permafrost, gas hydrates, unstable sediment conditions, pipelines, anchors, ordnance, shipwrecks, or other geophysical or man-made features.

In addition to relatively small airgun arrays, offshore site clearance surveys use various geophysical methods and tools to acquire graphic records of seafloor and sub-seafloor geologic conditions. The data acquired and the types of investigations outlined below are performed routinely prior to exploratory drilling and construction of production facilities in marine areas, and for submarine pipelines, port facilities, and other offshore projects. High-resolution geophysical data such as two-dimensional, high-resolution multi-channel seismic, medium penetration seismic, sub-bottom profiler, side scan sonar, multibeam bathymetry, magnetometer, and possibly piston core sediment sampling are typical types of data acquired. These data are interpreted to define geologic, geotechnical and archeological conditions at the site and to assess the potential engineering significance of these conditions. The following section provides a brief description of the operations and instrumentation used during Shell's 2010 site clearance program in the Beaufort Sea insofar as they may impact marine mammals.

The *Mt. Mitchell* and *Ocean Pioneer* were used as source vessels during marine survey activities in the Beaufort Sea in 2010. The *Arctic Seal* was responsible for re-supply and crew change support. Appendix D contains a description of the vessels used during Shell's marine surveys in the Beaufort and Chukchi seas in 2010.

All vessels operated in accordance with the provisions of the IHA issued by NMFS (Appendix A) and the LoA issued by the USFWS (Appendix B), as well as a Conflict Avoidance Agreement (CAA) between the seismic industry, the Alaska Eskimo Whaling Commission (AEWC), and the Whaling

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Captains Associations from Barrow, Nuiqsut, Kaktovik, Wainwright, Pt. Lay, and Pt. Hope (Appendix C). The CAA provided mitigation guidelines, including avoidance, to be followed by Shell while working in or transiting through the vicinity of active subsistence hunts. In particular, it addressed bowhead and beluga whale hunts and interactions with whaling crews, but was not limited to whaling activities. Under the terms of the CAA, communication centers (Com Centers) were established at Barrow, Wainwright, Point Hope, Deadhorse, and Kaktovik. The CAA outlined a communication program and specified locations and times when marine surveys could be conducted to avoid conflict with the subsistence hunts.

Operating Areas, Dates, and Navigation

Shell's marine surveys in the Beaufort Sea in 2010 were conducted on or near specific lease holdings in Harrison and Camden bays (Fig. 2.1). The *Mt. Mitchell* left Dutch Harbor on 27 Jul and arrived in Barrow on 2 Aug after transiting the Bering and Chukchi seas. The *Mt. Mitchell* was unable to access the survey area in Harrison Bay due to ice and weather conditions until 13 Aug. Shell's small seismic array was deployed and measurements of the underwater sound produced by a single 10–in^3 airgun and the four-airgun array (40–in^3) were conducted by JASCO on 13–14 Aug in Harrison Bay. JASCO calculated preliminary disturbance and safety radii within five days of completion of the measurements. These radii were the basis for implementation of mitigation by MMOs during airgun activities. Underwater sound propagation from the *Mt. Mitchell's* 3.5 kHz sub-bottom profiler was also measured by JASCO in Harrison Bay on 13–14 Aug. Shallow hazards surveys were conducted through 19 Aug but were suspended due to persistent ice conditions. The *Mt. Mitchell* returned to Barrow and to Dutch Harbor for a crew change and arrived back in Barrow on 11 Sep.

The *Mt. Mitchell* returned to Harrison Bay on 13 Sep and JASCO conducted measurements of underwater sound propagation from low-energy acoustic sources on the *Mt. Mitchell* including single- and multibeam sonars and a side-scan sonar. The lower-energy sources were used to conduct survey activities in Harrison and Camden bays through 9 Oct when weather conditions permitted. Airgun activity occurred only in Harrison Bay. The *Mt. Mitchell* terminated survey activities in the Beaufort Sea on 9 Oct and entered the Chukchi Sea on 10 Oct to conduct survey activities in the Chukchi Sea before returning to Dutch Harbor on 20 Oct.

On each seismic line in Harrison Bay, the airguns were firing for a period of time during ramp up, and during "lead in" periods before the beginning of seismic data acquisition at the start of each seismic line. The airguns were also firing during "lead out" periods after completion of each seismic line, before the full array was powered down to a single gun for transit to the next survey line. The *Mt. Mitchell's* airguns were operated along 1453 km (903 mi) of trackline in the Beaufort Sea in 2010. Periods of full array firing plus periods of lead in, lead out, and ramp up occurred along 1020 km (634 mi) of trackline. The single mitigation gun operated along 433 km (269 mi) of trackline.

Throughout the marine surveys the *Mt. Mitchell's* position, speed, and water depth were logged digitally every ~60 s. In addition, the position of the *Mt. Mitchell*, water depth, and information on the airgun array were logged for every airgun shot while the *Mt. Mitchell* was on a seismic line and collecting geophysical data. The geophysics crew kept an electronic log of events, as did the MMOs while on duty. The MMOs also recorded the number and volume of airguns that were firing when the *Mt. Mitchell* was offline (e.g., prior to shooting at full volume) or was online but not recording data (e.g., during airgun or computer problems).

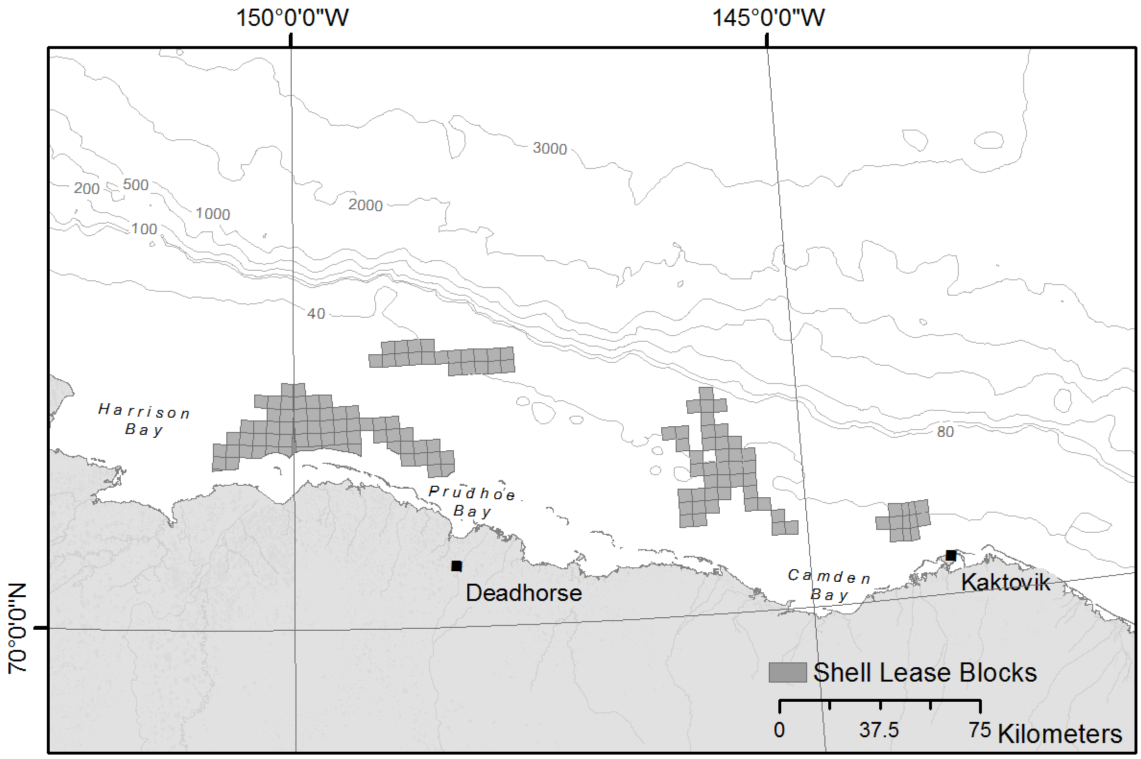


FIGURE 2.1. Location of Shell lease holdings in the Alaskan Beaufort Sea.

The *Ocean Pioneer* departed Dutch Harbor on 29 July and entered the Beaufort Sea on 17 Aug after completing sound source measurements in the Chukchi Sea. JASCO conducted Beaufort Sea measurements of sound propagation from the *Ocean Pioneer's* sub-bottom profiler and mini-cone penetrometer on 19 and 20 Aug in Camden Bay. JASCO made similar measurements of underwater sounds produced by the *Ocean Pioneer* itself and the sub-bottom profiler in Harrison Bay on 27 Aug. The *Ocean Pioneer* conducted marine surveys using these low-energy sources in Camden and Harrison bays from 18 to 27 Aug after which it departed the Beaufort Sea. The *Ocean Pioneer* returned to the Beaufort Sea on 17 Sep to conduct marine surveys from 18 Sep through 6 Oct and departed the Beaufort Sea on 7 Oct. Chapter 3 contains a complete description of measurements and analysis of sound sources on the *Mt. Mitchell* and *Ocean Pioneer*.

Airgun Description

The seismic source used by the *Mt. Mitchell* consisted of four 10-in^3 ariguns in an array with a total volume of 40 in^3. The array was towed ~16.5 m (54.1 ft) behind the *Mt. Mitchell* at a depth of ~2 m (6.6 ft). The same airgun array system was used for shallow hazards survey activities in the Chukchi and Beaufort seas in recent years. Air compressors aboard the *Mt. Mitchell* were the source of high pressure air used to operate the airgun arrays. Seismic pulses were emitted approximately every 20 m (66 ft) at intervals of ~9 sec while the *Mt. Mitchell* traveled at a speed of 4 to 5 knots (7.4–9.3 km/h, 4.6–5.8 mi/h). In general, the *Mt. Mitchell* towed the array along a predetermined survey track, although adjustments were occasionally made during the field season to avoid obstacles or during repairs to the equipment. Characteristics of the airgun arrays are detailed in Appendix D.

Geophysical Tools for Marine Surveys

In addition to the airgun array, the *Mt. Mitchell* also operated a 3.5 kHz sub-bottom profiler, a Reson SeaBat 8101 multibeam echosounder, and Odom Echotrac CVM single-beam echosounder, and EdgeTech 4200-MP dual frequency 100/400 kHz side-scan sonar. Source equipment onboard the *Ocean Pioneer* included an EdgeTech 3100 sub-bottom profiler and a Kongsberg EM3002 multibeam sonar. Several sound sources were associated with the AUV which was deployed from the *Ocean Pioneer*. These included an EdgeTech 216 single head sub-bottom profiler, an EdgeTech dual frequency 120/410 side scan sonar, and Kongsberg EM2000 multibeam sonar. The *Ocean Pioneer* also had a Vibracore vibratory coring system comprised of a NAVCO BH-8 pneumatic vibrator and steel coring tube for sediment core sampling.

Chukchi Sea Marine Surveys

Shell's marine surveys in the Chukchi Sea in 2010 were conducted on or near specific lease holdings within MMS Lease Sale 193 (Fig. 2.2). Shell conducted marine surveys in the Chukchi Sea in 2010 from the *Mt. Mitchell* and the *Ocean Pioneer*. Shell's marine surveys in the Chukchi Sea in 2010 did not involve any airgun activity. Most marine survey activity in the Chukchi Sea in 2010 was conducted by the *Ocean Pioneer*. The *Mt. Mitchell* assisted the *Ocean Pioneer* near the end of the 2010 field season.

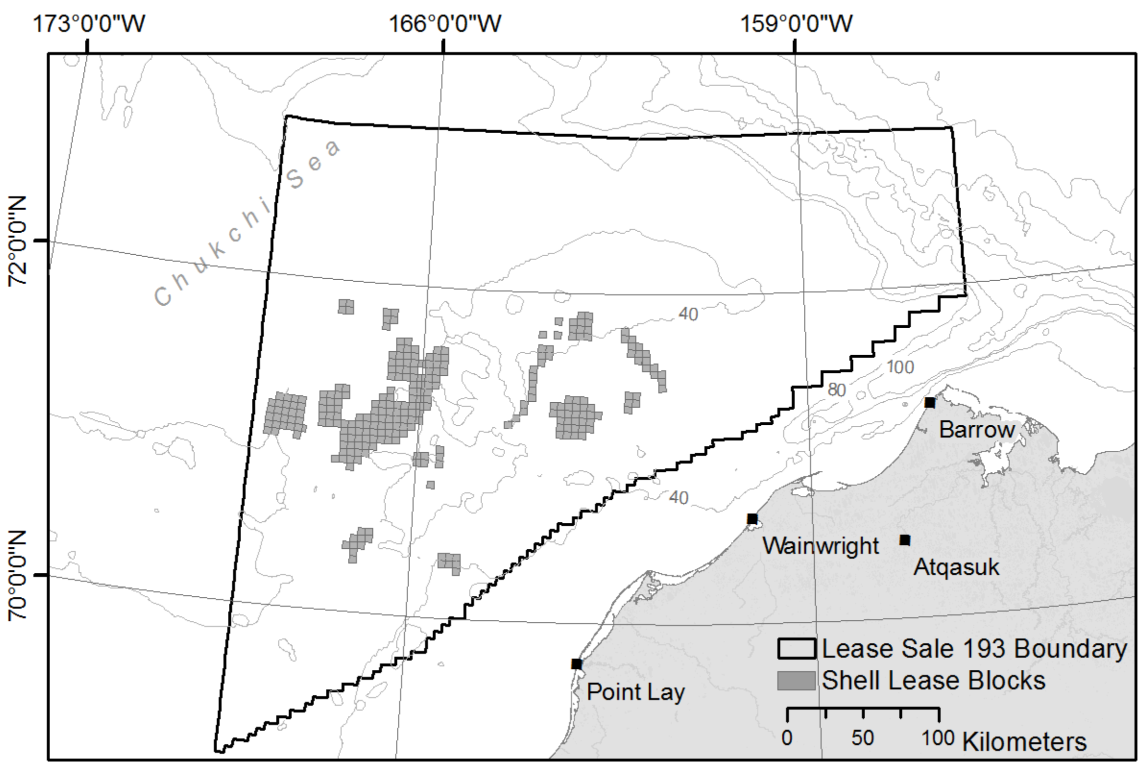


FIGURE 2.2. Location of Shell lease holdings in the Alaskan Chukchi Sea.

Operating Areas, Dates, and Navigation

The *Ocean Pioneer* arrived in the Chukchi Sea on 4 Aug. JASCO conducted measurements of underwater sound propagation from sound source equipment on the *Ocean Pioneer* including a sub-bottom profiler and multibeam sonar, and source equipment associated with the AUV including a single head sub-bottom profiler, multibeam sonar and side-scan sonar during 6–8 Aug near the Burger prospect.

Underwater sound propagation from the Vibracore coring system was also measured during this time period. The *Ocean Pioneer* transited to Nome after completion of the sound source measurements for a crew change after which she transited to the Beaufort Sea and returned to Nome on 31 Aug. The Ocean Pioneer departed Nome on 2 Aug and conducted marine surveys on or near Shell lease holdings in the Chukchi Sea from 4 through 16 Sep after which she returned to the Beaufort Sea. The Ocean Pioneer transited through the Chukchi Sea to Nome from 7–10 Oct. A final attempt to acquire survey data from 13–16 Oct was precluded by poor weather conditions and the *Ocean Pioneer* returned to Dutch Harbor on 20 Oct.

After leaving Dutch harbor on 27 July, the *Mt. Mitchell* transited the Chukchi Sea to conduct operations in the Beaufort Sea. The *Mt. Mitchell* spent some time in the Chukchi Sea from 8 to 11 Aug waiting for weather conditions to improve in the Beaufort Sea, and it transited the Chukchi Sea in early Sep for a crew change at Dutch Harbor and then returned to the Beaufort Sea. The *Mt. Mitchell* returned to the Chukchi Sea on 10 Oct and conducted ice gouge surveys from 10–12 Oct after which poor weather conditions precluded further survey activity. The *Mt. Mitchell* departed the Chukchi Sea and arrived in Dutch Harbor on 20 Oct.

The position, speed, and water depth were logged digitally every ~60 s throughout the *Ocean Pioneer* and *Mt. Mitchell* surveys. The geophysics crew kept an electronic log of events, as did the marine mammal observers (MMOs) while they were on duty.

Geophysical Tools for Marine Surveys

Geophysical equipment used for marine surveys in the Chukchi Sea was the same as that described above for the *Mt. Mitchell* and *Ocean Pioneer* in the Beaufort Sea. The airgun array used by the Mt. Mitchell in the Beaufort Sea however, was not used in the Chukchi Sea. Characteristics of this equipment are described in more detail in Appendix D.

Marine Mammal Monitoring and Mitigation

Vessel based monitoring

Vessel–based marine mammal monitoring and mitigation was conducted from the source vessels *Mt. Mitchell* and *Ocean Pioneer*, and from the supply vessel *Arctic Seal* throughout the survey operations in the Beaufort and Chukchi seas. Chapter 4 provides a detailed description of the methods and equipment used for monitoring and mitigation during the marine surveys, as well as the data analysis methodology. Results of the vessel–based monitoring program are presented in Chapters 5 and 7.

Aerial Monitoring

Shell conducted aerial surveys in support of the *Mt. Mitchell's* airgun activities during shallow hazards surveys in the Beaufort Sea. A series of north–south transect lines was established to monitor the areas where Shell planned to conduct shallow hazard and site clearance surveys. The aerial surveys were conducted using a Twin Otter fixed-wing aircraft flown at 1000 ft above ground level at airspeed of approximately 120 knots. The aerial survey program in support of Shell's shallow hazards surveys in the Beaufort Sea in 2010 began on 16 Jul and was completed on 10 Oct. A description of the aerial survey equipment, methods and the monitoring results is presented in Chapter 6.

Communications with Subsistence Hunters and Communication Centers

While working in the Alaskan Chukchi and Beaufort Seas, personnel contracted by Shell (most often the MMOs) aboard the three vessels routinely contacted native communities via com centers established at Point Hope, Wainwright, Barrow, Deadhorse, and Kaktovik. These communications were intended to ensure that project activities did not interfere with subsistence hunting along the coast.

Communications were made via phone or email by each vessel every six hours. Information reported during each communication included the current vessel location, activity, and heading, and the proposed activities for the next 24 hr.

The *Mt. Mitchell* encountered a group of seal hunters from Nuiqsut during its sound source verification (SSV) in Harrison Bay, Beaufort Sea, on 13 Aug. An Inupiat MMO established vhf radio communications with the hunters and confirmed that the vessel's activities were not interfering with subsistence activities. The subsistence hunters assisted the *Mt. Mitchell* later in the day by reporting the location of a missing buoy that had been taken by moving ice. There were no other on-water interactions between Shell vessels and subsistence hunters, and there were no reported conflicts between Shell vessels and subsistence hunters during 2010 Chukchi and Beaufort seas marine surveys.

3. UNDERWATER SOUND MEASUREMENTS[1]

This chapter presents the results of an underwater acoustic study designed to characterize the sound emissions of vessels and equipment involved in Shell Exploration and Production Company's 2010 marine surveys in the Alaskan Chukchi and Beaufort Seas. The study was performed by JASCO Applied Sciences to address the underwater noise monitoring requirements of Shell's Incidental Harassment Authorization (IHA). The marine survey programs referred to in the IHA included the Shallow Hazards and site clearance program and the Geotechnical Development program. The Shallow Hazards program involved use of small airgun systems and sub-bottom profiling sonar to identify near-seafloor geological features that could complicate drilling operations. The Geotechnical Development program used side-scan, single beam and multibeam sonar to investigate structures on the seafloor including strudel scour and ice gouge features.

Conditions 7(c), 9(a), and 9(b) of the IHA define the reporting requirements for sound characterization measurements (see excerpts in italics below). Field reports were delivered within 5 days of the measurements as per section 7. This chapter addresses the detailed reporting tasks of condition 9, and provides greater detail regarding the measurements performed under condition 7:

7. Monitoring

(c) Field Source Verification: Using a hydrophone system, the holder of this Authorization is required to conduct sound source verification tests for all seismic sources and source vessels not previously measured and, at a minimum, report the following results within 5 days of completing the test:

(i) Shell shall conduct empirical measurements of the distances in the broadside and endfire directions at which broadband received levels reach 190, 180, 170, 160, and 120 dB re 1 μPa (rms) for the energy source array combinations that may be used during the survey activities. The configurations shall include at least the full array and the operation of a single source that will be used during power downs.

(ii) Power density spectra (frequency spectra) of high frequency active acoustic sources (operating frequency> 180 kHz) that will be used in Shell's marine surveys will also be measured against ambient background noise levels and reported in 1/3-octave band and I-Hz band between 10 Hz and 180 kHz. …

9. Reporting

(a) Sound Source Verification and the distances to the various isopleths and power density spectra of high frequency active acoustic sources are to be reported to NMFS within five (5) days of completing the measurements. In addition to reporting the radii of specific regulatory concern, distances to other sound isopleths down to 120 dB rms (if measurable) will be reported in increments of 10 dB.

(b) Seismic Vessel Monitoring Program: A draft report will be submitted to the Director, Office of Protected Resources, NMFS, within 90 days after the end of Shell's 2010 open water marine survey program in the Beaufort and Chukchi Seas. The report will describe in detail: (i) the operations that were conducted; (ii) the results of the acoustical measurements to verify the safety radii; (iii) the methods, results, and interpretation pertaining to all monitoring tasks;…

[1] By Nicole E. Chorney, Graham Warner, Jeff MacDonnell, Andrew McCrodan, Terry Deveau, Craig McPherson, Caitlin O'Neill, David Hannay, Brendan Rideout (JASCO Applied Sciences).

The Geotechnical Development program sound source measurements were conducted in the Alaskan Chukchi and Beaufort Seas in August and September of 2010. The Shallow Hazards source measurements were performed only in Harrison Bay, Beaufort Sea. All measurements were made with calibrated sound recording equipment deployed to the seabed or over the side of support vessels near each of the operations monitored. The seabed-deployed recorders were JASCO Ocean Bottom Hydrophone (OBH) systems. Generally, low-frequency sources (< 24 kHz) were monitored with OBHs while higher-frequency sources were monitored with the vessel-deployed hydrophone.

The sources measured from the Geotechnical Development program included: the *R/V Ocean Pioneer* survey vessel, a vibratory coring system, sub-bottom profilers, multibeam sonar, side-scan sonar, AUV acoustic communication system, Doppler velocity logger and mini-cone penetrometer. Sources measured for the Shallow Hazards Program included: the *R/V Mt. Mitchell* survey vessel, 10 in^3 mitigation airgun, 40 in^3 airgun array, sub-bottom profiler, and multibeam, single-beam, and side-scan sonar. The specific source models and their specifications are described in detail later in this chapter.

In addition to the information required by the IHA, we have included a comparison of the threshold distances from the 2010 airgun source measurements with measurements of the same sources performed for Shell's Shallow Hazards programs in the Chukchi and Beaufort since 2007. These additional results show the variability of received sound levels for similar sources operating at different locations.

Goals of the Acoustics Program

The goals of the acoustic source verification program included:

1. Establishing the distances from airgun array sources that rms sound levels reached threshold levels between 190 dB re 1 μPa (rms) and 120 dB re 1 μPa (rms) in 10 dB steps. These distances were used to define exclusion zones that were implemented in the field by marine mammal observers onboard the work and survey vessels.
2. Characterize the source spectra (1-Hz band), 1/3-octave band levels, broadband source levels and broadband received levels of the active sonar including single beam, multibeam and side-scan sonar. For sonar with operating frequencies below 180 kHz (the maximum audible frequency for high-frequency marine mammal listeners), determine the distances at which sound levels exceed thresholds above 120 dB re 1 μPa (rms) in 10 dB steps.
3. For sonar operating above 180 kHz, investigate the spectral characteristics to determine if detectable sound emissions occurred below 180 kHz.
4. Measure source levels and distances to sound level thresholds from the vessels used for Shell's marine survey programs.
5. Characterize sound amplitude and spectral content of sounds from sources other than the sonar, airgun systems and vessels discussed above.

Methods

Sound Sources Monitored

A total of sixteen sound sources were measured during this source characterization program. The measurements were made in Aug and Sep 2010. The source measurements are summarized in Table 3.1, arranged by program, location, and date. The OBH deployments, high-frequency measurements and SSV tracks are numbered for ease o f reference, and each is described in the *Acoustic Monitoring Configurations* section.

TABLE 3.1. Sound sources monitored during Geotechnical Development Program and Shallow Hazards Program SSVs, Aug–Sep 2010, arranged by location and measurement date. Sources were monitored during one or more of five ocean bottom hydrophone deployments (OBH Depl) and four high-frequency monitoring system measurements (HiFreq). SSV Tracks by the survey vessels and AUV are numbered 1 through 12.

Location	Source	Date (2010)	Measurement	SSV Track
Geotechnical Development Program				
Burger Lease, Chukchi Sea	*R/V Ocean Pioneer*, transiting 10 kts	5 Aug	OBH Depl 1	1
	R/V Ocean Pioneer, in DP mode	6 Aug	OBH Depl 1	-
	Vibracore	6 Aug	OBH Depl 1	-
	Multibeam sonar, vessel-mounted	6 Sep	HiFreq 1	-
	Sub-bottom profiler, towfish	6 Sep	OBH Depl 2	2
	Acoustic comm signal to AUV	7 Sep	OBH Depl 2	3
	Multibeam sonar, AUV	7, 8 Sep	HiFreq 2, 3	4
	Doppler velocity log, AUV	7, 8 Sep	HiFreq 2, 3	4
	Sub-bottom profiler, AUV	8 Sep	HiFreq 3	-
	Side-scan sonar, AUV	8 Sep	HiFreq 3	-
Camden Bay, Beaufort Sea	Mini cone penetrometer	19 Aug	OBH Depl 3	-
	R/V Ocean Pioneer, transiting 3.2 kts	19 Aug	OBH Depl 3	5
	Sub-bottom profiler, towfish	20 Aug	OBH Depl 3	6
Harrison Bay, Beaufort Sea	*R/V Ocean Pioneer*, transiting 3.4 kts	27 Aug	OBH Depl 4	7
	Sub-bottom profiler, towfish	27 Aug	OBH Depl 4	7
Shallow Hazards Program				
Harrison Bay, Beaufort Sea	*R/V Mt. Mitchell*, transiting 4 kts	13 Aug	OBH Depl 5	8
	Airgun array (40 in^3)	13 Aug	OBH Depl 5	8
	Single airgun (10 in^3)	13 Aug	OBH Depl 5	9
	Sub-bottom profiler, vessel-mounted	13 Aug	OBH Depl 5	9
	R/V Mt. Mitchell, transiting 10 kts	14 Aug	OBH Depl 5	13
Mauya Prospect, Beaufort Sea	Multibeam sonar, vessel-mounted	15 Sep	HiFreq 4	10–12
	Single-beam sonar, vessel-mounted	15 Sep	HiFreq 4	10–12
	Side-scan sonar, towfish	15 Sep	HiFreq 4	10–12

Geotechnical Development Program Sources

R/V Ocean Pioneer

The *R/V Ocean Pioneer* is a 205-ft research/supply vessel with a 40-ft beam, 17-ft depth and 14-ft draft (Fig. 3.1) operated by Stabbert Maritime. It has two Alco 12-251 main engines driving two electronic variable pitch props, with 5600 HP (at 900 rpm) total horsepower (Stabbert Maritime 2009).

FIGURE 3.1. The *R/V Ocean Pioneer*, a 205-ft research vessel used as the main work vessel for the Geotechnical Development Program (photo source: http://www.stabbertmaritime.com).

Vibracore, Vibratory Coring System

Vibracore sediment core sampling was performed to collect geotechnical information about the seabed near Shell's lease areas in the Chukchi Sea. Greg Drilling operated an Alpine Vibracore with 20-ft core pipe length. This system comprises a NAVCO BH-8 pneumatic vibrator attached to a sprung plate that impacts the top of the steel coring tube (Fig. 3.2, Gregg Drilling 2010). The vibratory impacts cause the pipe to penetrate the upper seabed layers and a core sample is collected inside the pipe. There is strong acoustic coupling between the vibrator and water because the entire apparatus is submerged during operation. The sounds produced consist of a series of impulses corresponding to the movement and impacts of the vibrator on the pipe.

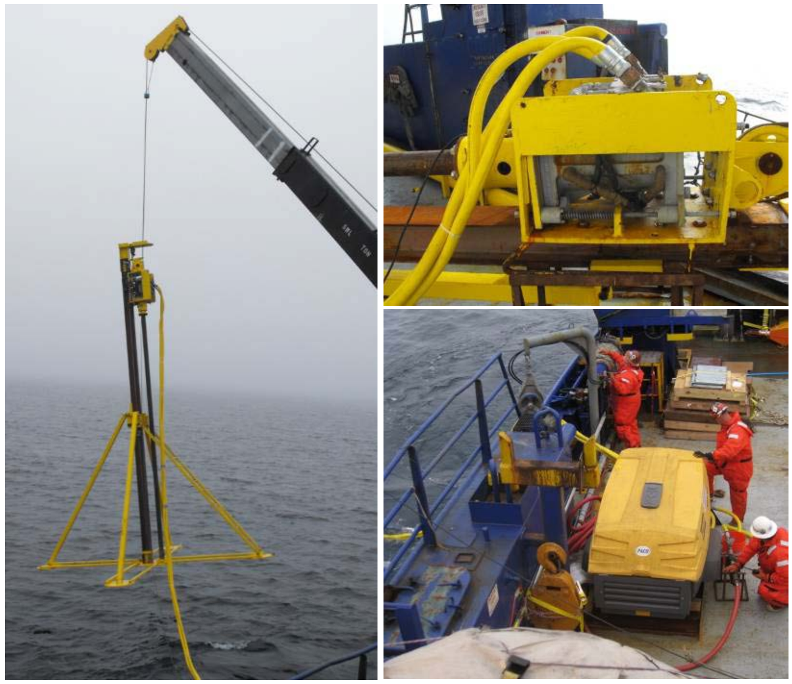


FIGURE 3.2. Gregg Drilling's 20-ft Alpine Vibracore system (left), and its pneumatic vibrator (above right) and air compressor (below right) deployed from the *Ocean Pioneer*.

Mini-Cone Penetrometer

Cone penetrometer testing (CPTs) were performed by Gregg Drilling with a mini-cone penetrometer (mini-CPT). The device includes a 3-hp single phase Franklin Waterwell hydraulic pump motor, operating at 240 V that drives a ¾"-tip penetrometer into the seabed to a penetration depth of up to 10 m. The apparatus was lowered to the seabed with a crane, while the vessel held position in DP mode.

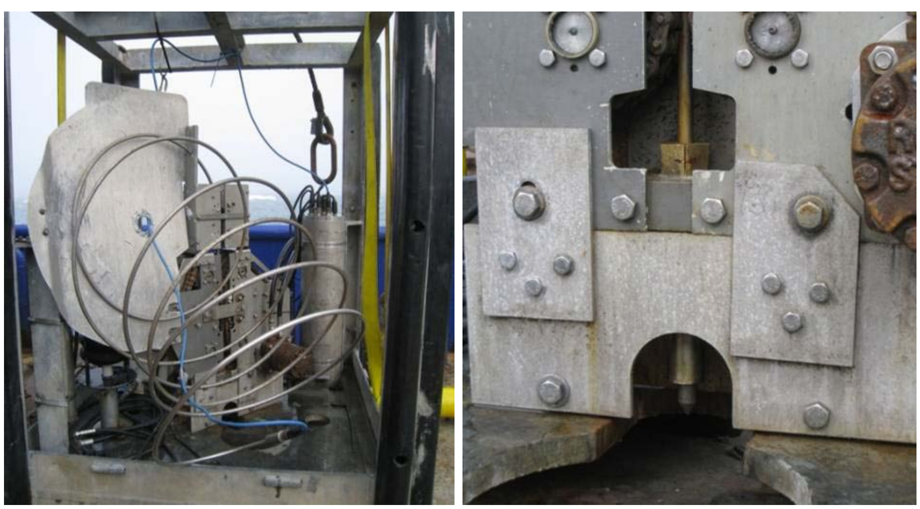


FIGURE 3.3. Gregg Drilling's mini-CPT (left) and close-up of the penetrometer tip (right), deployed from the *Ocean Pioneer*.

Sonar Sources

During the Geotechnical Development Program, active sonar sources were operated from both the *Ocean Pioneer* and an autonomous underwater vehicle (AUV). These sources include a sub-bottom profiler towfish (EdgeTech 3100 SB-216S, Fig. 3.4 (left)), a vessel-mounted (port midship) multibeam sonar (Kongsberg EM 3002, Fig. 3.4 (right)), and a sub-bottom profiler, multibeam sonar, and side-scan sonar onboard the AUV (Fig. 3.5). The manufacturer and model of each sonar source are given in Table3.2 along with the frequencies of operation during the program. Measurements of the sound levels of the sub-bottom profilers were made with OBHs. Sonar measurements were made using a high-frequency monitoring system with hydrophone deployed from the research vessel. Acoustic recordings of these measurements also captured sound produced by the AUV acoustic communication signal and the Doppler velocity log (DVL). The acoustic communication signal is used to send commands and information between the AUV and the operator on the vessel. The DVL uses an acoustic signal to track its position for navigation purposes. Sounds from these two sources were analyzed.

FIGURE 3.4. EdgeTech 3100 SB-216S sub-bottom profiler towfish (left) and Kongsberg EM 3002 multibeam sonar (right, photo source: http://www.gserentals.co.uk).

FIGURE 3.5. Kongsberg HUGIN 1000 autonomous underwater vehicle (AUV) with onboard sub-bottom profiler, multibeam sonar and side-scan sonar (photo source: http://www.km.kongsberg.com).

TABLE 3.2. Geotechnical Development Program sonar sources, employed and measured Aug–Sep 2010, and the frequencies at which they were operated.

Source	Manufacturer	Model	Frequency (kHz)
Sub-bottom profiler, towfish	EdgeTech	3100 SB-216S	3–12
Sub-bottom profiler, AUV	EdgeTech	216	3–7
Multibeam sonar, vessel-mounted	Kongsberg	EM 3002	300
Multibeam sonar, AUV	Kongsberg	EM 2000	200
Side-scan sonar, AUV	EdgeTech	Dual frequency	410
Communication signal, AUV			20–24
Doppler velocity log, AUV	RD Instruments	WHN 300	300

<u>*Shallow Hazards Program Sources*</u>

R/V Mt. Mitchell

The *R/V Mt. Mitchell* is a 231-ft research vessel with a 42-ft beam and 13-ft draft (Fig. 3.6) operated by Global Seas. It has two EMD/567C General Motors main diesel engines, each 1200 HP, driving two variable pitch 8.5-ft diameter propellers (Global Seas 2010).

FIGURE 3.6. The *R/V Mt. Mitchell*, a 231-ft research vessel.

Seismic Airguns

The airgun array consisted of four 10 in^3 airguns (Fig. 3.7), towed 16.5 m aft of the *Mt. Mitchell* at 2 m depth. Fig. 3.8 shows the relative positions of the airguns in the array. The airguns were alternated in periodically during the single 10 in^3 mitigation airgun test to prevent uneven airgun wear and to prevent the airguns from flooding. All four airguns were operated together for the 40 in^3 configuration.

FIGURE 3.7. Airgun array aboard the *Mt. Mitchell* before deployment.

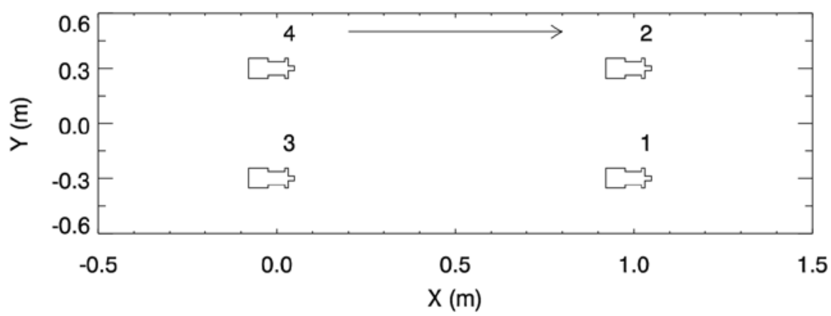
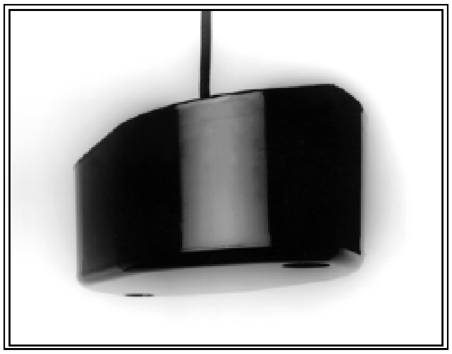


FIGURE 3.8. Airgun layout for the system tests. Each gun has a volume of 10 in^3, with a total array volume of 40 in^3. Arrow indicates tow direction.

Sonar Sources

Sonar sources employed during the Shallow Hazards Program include a vessel-mounted sub-bottom profiler (GeoAcoustics/Kongsberg GeoPulse, port midship, Fig. 3.9 (left)), pole-mounted multibeam sonar (RESON SeaBat 8101, starboard midship, Fig. 3.9 (right)), a pole-mounted single-beam sonar (Odom Echotrac CVM, port midship, Fig. 3.10 (left)), and a side-scan sonar towfish (EdgeTech 4200-MP Dual frequency, Fig. 3.10 (right)). The manufacturer and model of each sonar source are given in Table 3.3 along with the frequencies at which they were operated during the program.

FIGURE 3.9. GeoAcoustics/Kongsberg GeoPulse sub-bottom profiler (left) and RESON SeaBat 8101 multibeam sonar (right, photo source: http://www.seafloorsystems.com).



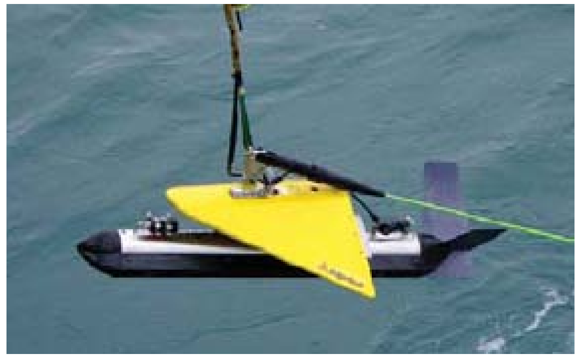


FIGURE 3.10. Odom Echotrac CVM single-beam sonar OTSBB200/24-4/20 dual-frequency transducer (left, photo source: http://www.odomhydrographic.com) and EdgeTech 4200-MP Dual frequency side-scan sonar (right, photo source: http://www.edgetech.com).

TABLE 3.3. Shallow Hazards Program sonar sources, employed and measured Aug and Sep 2010, and frequencies at which they were operated.

Source	Mounting	Manufacturer	Model	Frequency (kHz)
Sub-bottom profiler	Pole, port midship	GeoAcoustics	GeoPulse	3.5
Multibeam sonar	Pole, starboard midship	RESON	SeaBat 8101	240
Single-beam sonar	Pole, port midship	Odom	Echotrac CVM, OTSBB200/ 24-4/20 transducer	200
Side-scan sonar	Towfish	EdgeTech	4200-MP Dual frequency	120*, 400

** Measured central frequencies; manufacturer specifications state 100 and 400 kHz.*

Acoustic Monitoring Equipment

Sound sources from the Geotechnical Development and Shallow Hazards Programs with frequencies below 24 kHz were monitored using JASCO's OBH recording systems deployed to the seabed. The sources in this category include: survey vessel self-noise, seismic airguns, Vibracore, mini-cone penetrometer, sub-bottom profilers and AUV communications signals. Sound sources at frequencies above 24 kHz were monitored with a high-frequency monitoring system, which records frequencies up to 500 kHz. The high frequency sources include: multibeam, single-beam and side-scan sonar and Doppler velocity log (either vessel-mounted or onboard the AUV).

Ocean Bottom Hydrophones (OBH)

The SSVs for both the Geotechnical Development and Shallow Hazards Programs employed JASCO autonomous Ocean Bottom Hydrophone (OBH) recording systems (Fig. 3.11, two units per Program) to monitor sound levels at frequencies up to 24 kHz. Signals from RESON TC 4032 and TC 4043 hydrophones (-170 and -201 dB re 1 V/µPa nominal sensitivities, respectively) were digitized (24-bit) and recorded on Sound Device 722 Recorders, at a sample rate of 32 or 48 kHz, depending on the sound source of interest. The hydrophones and recorders are powered by alkaline battery packs, providing a recording lifetime of 50–60 h, depending on sample rate.

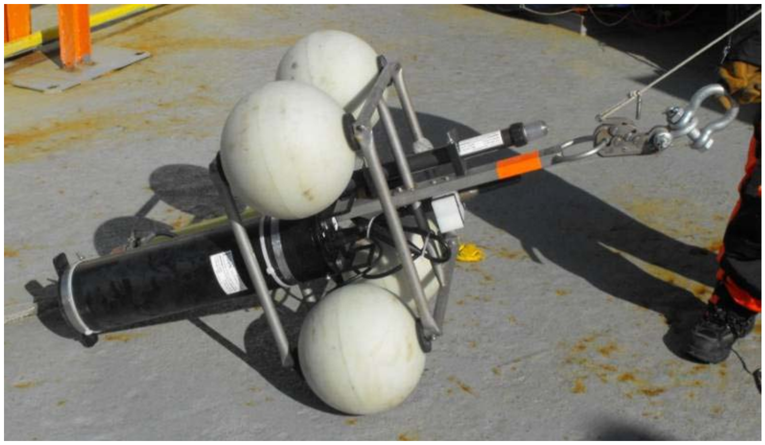


FIGURE 3.11. J ASCO's Ocean Bottom Hydrophone (OBH) system.

The OBH systems were calibrated using GRAS 42AA pistonphone precision sound source, which generates a 250 Hz tone with amplitude accurate to within ± 0.08 dB. The tone level is played directly to the hydrophone sensor using a specialized adapter. Calibrations were performed in the field prior to each measurement. The pistonphone reference signal is recorded by the digital recorders and this is later analyzed to provide end-to-end system calibration of hydrophone, amplifiers and digitization. See Appendix A for calibration logs and results for each of the 4 OBHs.

Global Positioning System (GPS) coordinates of deployment, vessel, and source locations were obtained with a Garmin GPSmap 76 or from the survey vessel's logs and are accurate to within 15 m.

High-Frequency Monitoring System

Side-scan, multibeam, single-beam and Doppler velocity log sonar sources were measured with a high-frequency acoustic monitoring system. This system incorporates a RESON TC 4014 hydrophone (-186 dB re 1 V/1 μPa nominal sensitivity) connected via undersea cable to a National Instruments data acquisition system (NIDAQ) and a field laptop for data storage. Pre-amplified analog signals from the hydrophone are 16-bit digitally sampled at 1 MHz sample rate to measure frequencies up to 500 kHz.

The system hydrophone was deployed to the full cable length over the side of the *Ocean Pioneer* during AUV operations and over the side of the *Arctic Seal* while measuring the *Mt. Mitchell* sonar systems. An anchor line was attached to the 13 m long undersea cable to keep the hydrophone as deep in the water as possible. GPS logs were recorded during measurements with a Garmin GPSmap-76 and are accurate to within 15 m.

Acoustic Monitoring Configurations

Sound measurements for the Geotechnical Development and Shallow Hazards Survey Programs were conducted in the Alaskan Beaufort and Chukchi seas. Fig. 3.12 shows all of the measurement locations listed in Table 3.1. Individual maps and details of each measurement location and methodology are provided in the sections that follow.

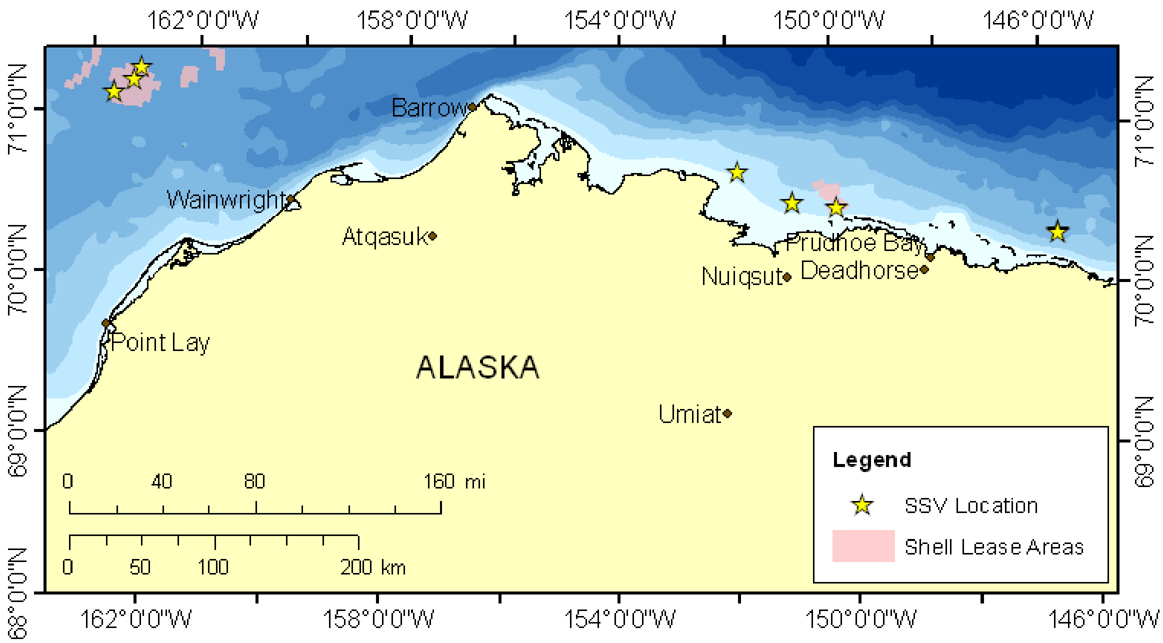


FIGURE 3.12. SSV locations in the Alaskan Chukchi and Beaufort Seas for the Geotechnical Development and Shallow Hazards Survey Programs.

Geotechnical Development Program

Burger Prospect, Chukchi Sea

OBH Deployment 1: 4–6 Aug, Ocean Pioneer self-noise, Vibracore

OBH systems S-02 and S-03 were deployed 4 Aug 2010 (Table 3.4) for SSVs of *R/V Ocean Pioneer* self-noise (during transit and in DP mode) and the Vibracore. They were positioned 50 and 200 m from core location BJ08_144A (Fig. 3.13) at 46 m water depth.

Ocean Pioneer SSV Track 1: The SSV of the *Ocean Pioneer* measured sounds from the vessel as it sailed a 14.8-km track line, beginning 9.8 km west and ending 5.0 km east of OBH S-03 (fig. 3.13), Table 3.5). The vessel took 47 min to transit SSV Track 1 at a nominal speed of 10 kts, with an engine speed of 800 rpm with 80% pitch setting of the propellers. GPS locations were tracked on the bridge and shifted 38 m to correspond to the relative location of the aft propellers. The horizontal range between the vessel propellers and the deployment location of S-03 was calculated from GPS position coordinates.

TABLE 3.4. OBH Deployment 1 locations and times (AKDT), 4 Aug at Burger Prospect, including distance from coring site BJ08_144A.

OBH	Deployment (4 Aug)	Latitude	Longitude	Water depth (m)	Range from coring site (m)	Record start (4 Aug)	Record end (6 Aug)
S-03	19:47	71°11.534' N	163°31.056' W	46	58	18:19	22:23
S-02	19:08	71°11.538' N	163°30.814' W	46	202	18:06	20:47

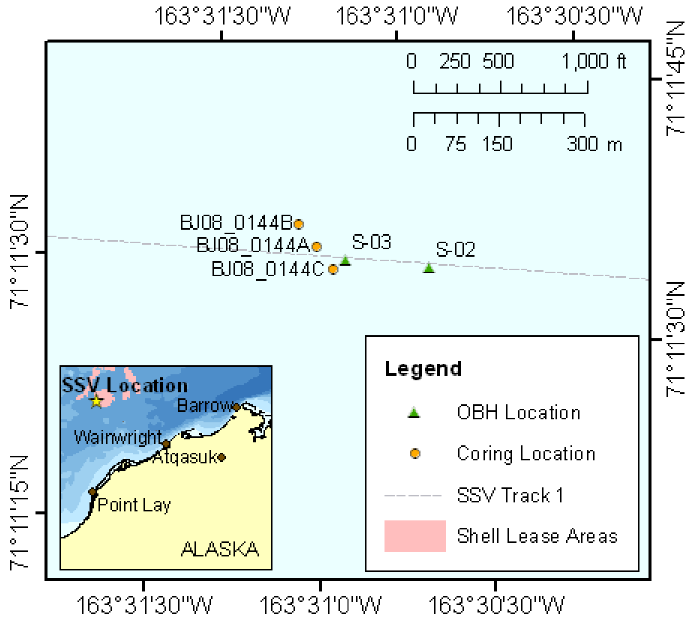


FIGURE 3.13. OBH Deployment 1 at Burger Prospect relative to core locations BJ08_144A–C and *Ocean Pioneer* SSV Track 1.

TABLE 3.5. Ocean Pioneer SSV Track 1, 5 Aug at Burger Prospect, at 10 kts nominal speed. Times are AKDT.

Event	Time	Latitude	Longitude	Range from S-03 (m)
Track 1 start	09:32	71°11.135′ N	163°47.362′ W	9840
CPA to S-03	10:03	71°11.533′ N	163°30.949′ W	25
Track 1 end	10:19	71°11.733′ N	163°22.6377′ W	5020

Vibracore, Ocean Pioneer DP mode: The Vibracore system was deployed at site BJ08_144A (Fig. 3.13), while the *Ocean Pioneer* held position in Dynamic Positioning (DP) mode. The vibratory hammer was turned on while the system was above water, suspended by crane, and the system was then lowered through water column for about 3 min before coming to rest on the seabed. It remained on the seabed for about 7 min, before being raised back out of the water. OBH acoustic measurements of the *Ocean Pioneer* in DP mode were captured before during and after the Vibracore deployment.

***OBH Deployment 2:* 6-7 Sep, Ocean Pioneer w/ sub-bottom profiler, AUV comm signal**

OBH system S-03 was deployed 6 Sep 2010 (Table 3.6) for SSV measurements of *Ocean Pioneer* SSV Track 2 with sub-bottom profiler towfish and AUV SSV Track 3.

TABLE 3.6. OBH Deployment 2 location and time (AKDT), 6 Sep at Burger Prospect.

OBH	Deployment (6 Sep)	Latitude	Longitude	Water depth (m)	Record start (6 Sep)	Record end (7 Sep)
S-03	21:39	71°17.100’ N	163°11.520’ W	50.9 m	19:27	22:56

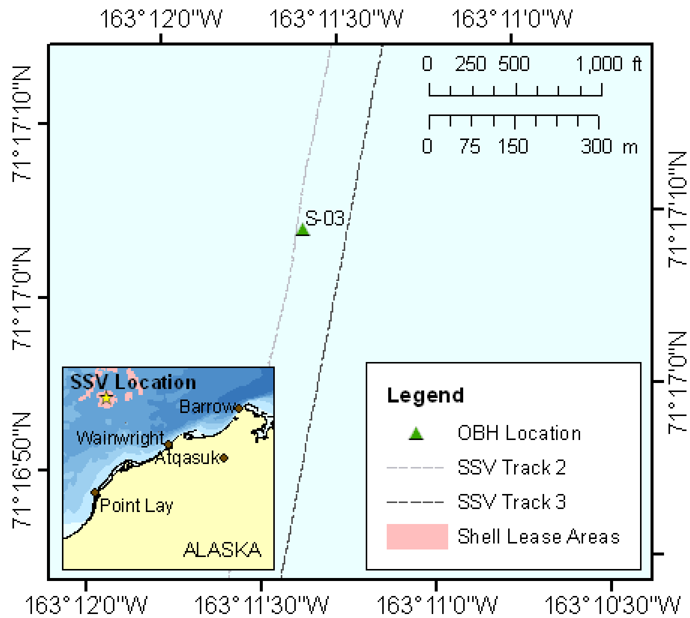


FIGURE 3.14. OBH Deployment 2 at Burger Prospect relative to *Ocean Pioneer* SSV Track 2 and AUV SSV Track 3.

Ocean Pioneer SSV Track 2: The sub-bottom profiler towed behind the *Ocean Pioneer* was recorded as the vessel traversed a 7.6 km track line, beginning 2.6 km south, passing 13 m horizontally from, and ending 5 km north of OBH S-03 (Table 3.7, Fig. 3.14). The vessel took 71 min to transit the track line at a nominal speed of 2.3 kts.

TABLE 3.7. *Ocean Pioneer* SSV Track 2 with sub-bottom profiler, 6 Sep at Burger Prospect. Times are AKDT.

Event	Time	Latitude	Longitude	Range from S-03 (m)
Track 2 start	22:09	71.262° N	163.196° W	2600
CPA to S-03	22:33	71.285° N	163.192° W	13
Track 2 end	23:20	71.330° N	163.185° W	5000

AUV SSV Track 3: The AUV traversed a 13-km track line, starting 5 km north of OBH S-03, passing within 73 m horizontally from, and continuing 8 km south of the recorder (Table 3.8, Fig. 3.14). The AUV took 101 min to travel the track at a nominal speed of 3.2 kts. SSV Track 3 was intended to measure the AUV sub-bottom profiler, but the profiler was found to be non-operational during this test. The AUV sub-bottom profiler was successfully measured during High-Frequency Measurement 3. Recordings from SSV Track 3 were analyzed only for the AUV communications signal.

TABLE 3.8. AUV SSV Track 3, 7 Sep at Burger Prospect, which recorded the AUV communications signal. Times are AKDT.

Event	Time	Latitude	Longitude	Range from S-03 (m)
Track 3 start	11:19	71° 19.781' N	163° 11.000' W	5000
CPA to S-03	11:58	71° 17.099' N	163° 11.398' W	73
Track 3 end	13:00	71° 13.002' N	163° 12.000' W	7500

High-Frequency Measurement 1: 6 Sep, Multibeam sonar, vessel-mounted

Underwater sound levels were measured from the multibeam sonar mounted on the port side of the *Ocean Pioneer* on 6 Sep for 2 min (09:10–09:13 AKDT). The high-frequency hydrophone was deployed over the starboard rail, opposite the multibeam sonar mounted on the port side. The hydrophone was 14 m horizontally from the transducer of the sonar and at 6 m depth.

High-Frequency Measurement 2: 7 Sep, AUV multibeam, Doppler velocity log

AUV SSV Track 4: Acoustic sound levels from the AUV high-frequency sonar were measured during AUV SSV Track 4. The high-frequency monitoring system was deployed off the port side of the *Ocean Pioneer* as the AUV traversed four parallel 1-km track lines, with CPAs of 140, 240, 340 and 440 m (Table 3.9, Fig. 3.15). Due to rough seas, the hydrophone depth varied from 2 to 7 m. Acoustic measurements were obtained for only the multibeam sonar and Doppler velocity log, as the side-scan sonar was non-operational. The AUV side-scan sonar was successfully measured later during High-Frequency Measurement 3.

TABLE 3.9. AUV SSV Track 4 locations and times (AKDT) for the start and end and the CPA of each line, 7 Sep at Burger Prospect.

Event	Time	Latitude	Longitude	Range from hydrophone (m)
Track 4 start	16:09	71°22.126' N	163°03.445' W	417
CPA to hydrophone	16:12	71°22.002' N	163°03.859' W	243
CPA to hydrophone	16:19	71°22.040' N	163°03.973' W	341
CPA to hydrophone	16:30	71°22.084' N	163°04.078' W	442
CPA to hydrophone	16:37	71°22.041' N	163°03.970' W	341
CPA to hydrophone	16:47	71°22.003' N	163°03.856' W	242
CPA to hydrophone	16:55	71°21.962' N	163°03.742' W	140
CPA to hydrophone	17:05	71°22.004' N	163°03.854' W	242
Track 4 end	17:07	71°21.935' N	163°04.079' W	300

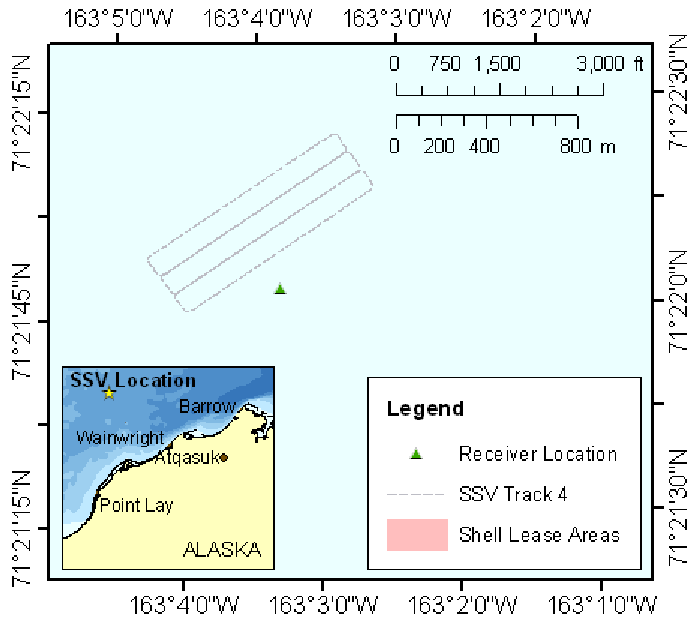


FIGURE 3.15. AUV SSV Track 4 for High-Frequency Measurement 2 of the multibeam and side-scan sonar, 7 Sep at Burger Prospect.

***High-Frequency Measurement 3*: 8 Sep, AUV side-scan sonar, multibeam sonar and Doppler velocity log**

The AUV sub-bottom profiler and side-scan sonar were found to be non-operational during AUV SSV Tracks 3 and 4, respectively, necessitating this SSV test. The high frequency monitoring hydrophone was deployed off the aft deck of the *Ocean Pioneer* while the AUV was towed behind the vessel (8 Sep, 23:25–23:53 AKDT). Due to the relative movement of the AUV and hydrophone, the range from the source transducers to the hydrophone varied from approximately 6–10 m. Sound levels were measured at a hydrophone depth of 1–2 m. The AUV–hydrophone geometry was most stable during the first 2 min of monitoring, so only measurements during this period were analyzed. The multibeam sonar was also operational during this test.

Camden Bay, Beaufort Sea

***OBH Deployment 3*: 18–20 Aug, Mini-CPT, Ocean Pioneer w/ sub-bottom profiler towfish**

OBH systems S-02 and S-03 were deployed in Camden Bay 18 Aug, 40 and 200 m from core location PR08_0030A, respectively (Table 3.10, Fig. 3.16).

Mini-CPT: Sound levels from the mini-CPT were measured 19 Aug at core location PR08_0030A, 40 m from recorder S-02. The mini-CPT was deployed by crane from the port side of the *Ocean Pioneer,* while the vessel held position in DP mode. Once lowered to the seabed, the mini-CPT hydraulic motor drove the cone penetrometer into the seafloor, reaching 1.7 m depth. Table3.11 outlines the timing of events during the operation.

TABLE 3.10. OBH Deployment 3 times (AKDT) and locations, 18 Aug in Camden Bay.

OBH	Deployment (18 Aug)	Latitude	Longitude	Water depth (m)	Range from coring site (m)	Record start (18 Aug)	Record end (20 Aug)
S-02	23:07	70°21.820' N	146°00.882' W	38	40	22:46	05:09
S-03	22:20	70°21.882' N	146°01.144' W	37	200	21:10	10:39

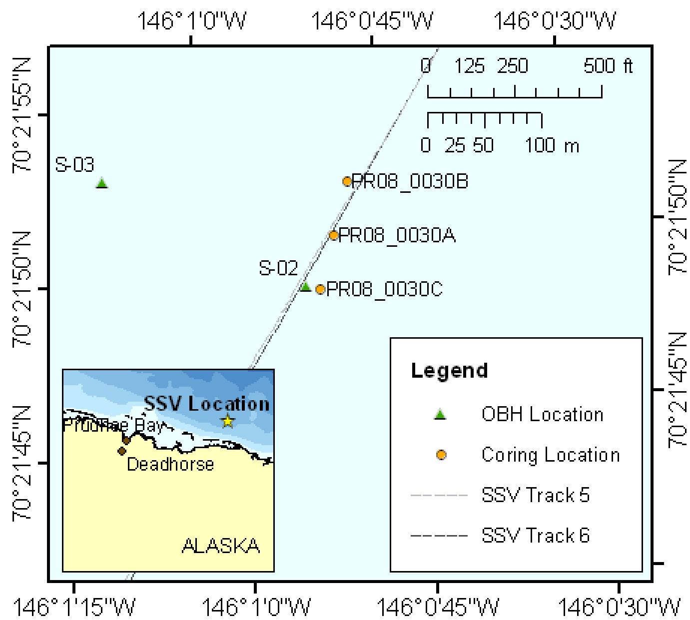


FIGURE 3.16. OBH Deployment 3 in Camden Bay relative to core locations PR08_0030A to C and to *Ocean Pioneer* SSV Tracks 5 and 6.

TABLE 3.11. Mini-CPT deployment times (AKDT), 19 Aug in Camden Bay.

Event	Time (hh:mm:ss)	Relative time (mm:ss)
Vessel in DP	16:58:36	-19:39
Mini-CPT over the side	17:11:45	-06:30
Mini-CPT on bottom	17:18:15	00:00
Mini-CPT raised from bottom	17:29:30	11:15
Vessel began transit to next site	17:40:27	22:12

Ocean Pioneer SSV Track 5: This SSV test was to monitor the sub-bottom profiler towed behind the *Ocean Pioneer* as it traversed a 9 .5 km track line, beginning 3 km southwest and ending 6.5 km northeast of S-02 (Fig. 3.16, Table 3.12). The CPAs to S-02 and S-03 were 23 m and 212 m, respectively. The vessel took 100 min to transit SSV Track 5 at a nominal speed of 3.2 kts. Acoustic measurements were obtained for only *Ocean Pioneer* self-noise, as the sub-bottom profiler was non-operational. The profiler was recorded opportunistically the following day during SSV Track 6 described later.

TABLE 3.12. *Ocean Pioneer* SSV Track 5, 19 Aug in Camden Bay. Times are AKDT. Sub-bottom profiler was non-operational.

Event	Time	Latitude	Longitude	Range from S-02 (m)	Range from S-03 (m)
Track 5 start	03:10	70°20.570' N	146°03.952' W	3000	1716
CPA	03:40	70°21.848' N	146°00.835' W	23	212
Track 5 end	04:51	70°24.657' N	145°54.784' W	6500	6509

Ocean Pioneer SSV Track 6: Sound levels of the sub-bottom profiler towfish were measured opportunistically during survey Line 522 in Camden Bay, 20 Aug (Fig. 3.16, Table 3.13). The vessel with profiler in tow traversed a 4.4-km track, starting 2 km southwest and ending 2.4 km northeast of S-03, with a CPA of 216 m. Sound levels were not recorded on S-02 due to battery depletion.

TABLE 3.13. *Ocean Pioneer* SSV Track 6, Survey Line 522 with sub-bottom profiler towfish, 20 Aug in Camden Bay. Times are AKDT.

Event	Time	Latitude	Longitude	Range from S-03 (m)
Line 6 start	07:50	70° 20.962' N	146° 02.746' W	2000
CPA to S-03	08:10	70° 21.832' N	146° 00.861' W	216
Line 6 end	08:32	70° 22.861' N	145° 58.640' W	2400

Harrison Bay, Beaufort Sea

***OBH Deployment 4*: Ocean Pioneer self-noise and sub-bottom profiler towfish**

OBH S-03 was deployed and retrieved 27 Aug in Harrison Bay for a dedicated SSV of the sub-bottom profiler towfish (Table 3.14, Fig. 3.17).

TABLE 3.14. OBH Deployment 4 time (AKDT) and location, 27 Aug in Harrison Bay.

OBH	Deployment (27 Aug)	Latitude	Longitude	Water depth (m)	Record start (27 Aug)	Record end (27 Aug)
S-03	12:29	70°53.811' N	151°48.780' W	19.5 m	11:53	17:45

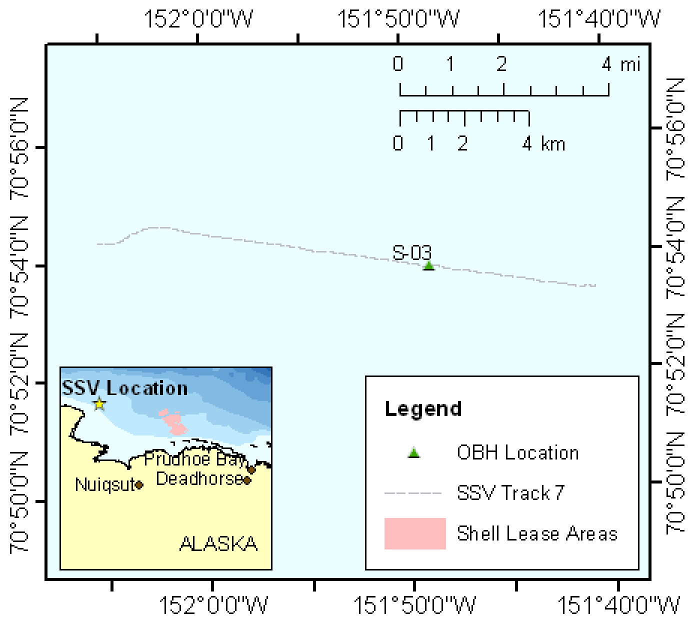


FIGURE 3.17. OBH Deployment 4 and *Ocean Pioneer* SSV Track 7 with sub-bottom profiler, 27 Aug in Harrison Bay.

Ocean Pioneer SSV Track 7: The *Ocean Pioneer* transited SSV Track 7 in Harrison Bay while towing the sub-bottom profiler with both propellers at 800–810 rpm, resulting in nominal speeds of 3.3–3.5 kts depending on the current. The sub-bottom profiler was towed 14 m from the stern of the *Ocean Pioneer* at a nominal depth of 5 m. It was operated at a frequency range of 3 to 12 kHz (different than the normal operational range of 2–16 kHz) due to the seabed composition in the survey area. Geo-survey data were recorded throughout the test tracks to confirm the profiler was fully operational. Sound levels were analyzed for both the sub-bottom profiler and *Ocean Pioneer* self-noise.

TABLE 3.15. *Ocean Pioneer* SSV Track 7, with sub-bottom profiler towfish, 27 Aug in Harrison Bay. Times are AKDT.

Event	Time	Latitude	Longitude	Range from S-03 (m)
Line 7 start	13:30	70°53.381' N	151°40.560' W	5070
CPA to S-03	14:18	70°53.802' N	151°48.780' W	16
Line 7 end	15:56	70°54.344' N	152°05.274' W	10,090

Shallow Hazards Program

Harrison Bay, Beaufort Sea

OBH Deployment 5: Mt. Mitchell self-noise, airguns, sub-bottom profiler

OBHs 1 and 2 were deployed 13 Aug, 0 m and 200 m from the survey line, respectively (Table 3.16, Fig. 3.18) near Mauya, Como, and Cornell North Prospects. The planned survey sites were inaccessible due to sea ice. Consequently the SSV test was performed to the west of the planned survey zones at a location chosen for maximum accessible depth to match most closely the depths at the survey sites.

Due to ice movement during the SSV, OBH 2 with a surface float was dragged 6.5 km from the deployment location. O BH 2 was successfully recovered, but its position throughout the SSV is unknown, so the data it collected were not analyzed. Data from OBH 1, which did not change position during the SSV, were sufficient to successfully complete the SSV.

TABLE 3.16. OBH Deployment 5 times (AKDT) and locations, 13 Aug in Harrison Bay.

OBH	Deployment (13 Aug)	Latitude	Longitude	Water depth (m)	Record start (13 Aug)	Record end (Aug 14)
1	13:23	70°40.830' N	150°49.018' W	15.3	12:30	03:18
2	14:06	70°40.939' N	150°49.003' W	15.2	12:30	05:16

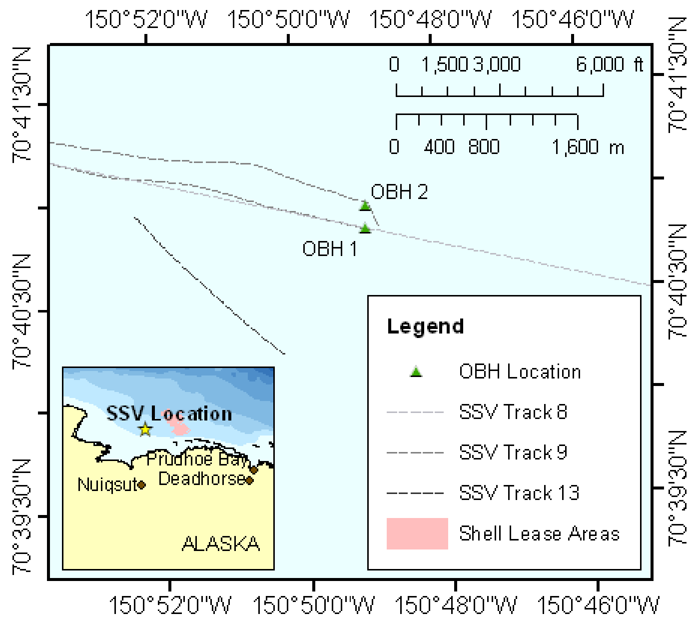


FIGURE 3.18. OBH Deployment 5 in Harrison Bay relative to *Mt. Mitchell* SSV Tracks 8 and 9 and proposed prospect survey lines.

***Mt. Mitchell* SSV Track 8**: The *Mt. Mitchell* transited at 4 kts from point A to B, giving a 5 km approach to and 20 km departure from OBH 1 (Table 3.17). The airgun array (40 in^3) was towed 16.5 m aft of the *Mt Mitchell* at 2 m water depth. The airguns were fired every 20 m (about every 9 s).

TABLE 3.17. *Mt. Mitchell* SSV Track 8, with airgun array at 4 kts nominal speed, 13 Aug in Harrison Bay. Times are AKDT.

Event	Time	Latitude	Longitude	Range from OBH 1 (m)
Line 8 start (A)	16:30	70°40.137' N	150°40.906' W	5160
CPA to OBH 1	17:16	70°40.826' N	150°49.002' W	12(slant)
Line 8 end (B)	19:59	70°43.560' N	151°20.595' W	20,100

***Mt. Mitchell* SSV Track 9**: The *Mt. Mitchell* transited from point B toward point A (Table 3.18), firing a single mitigation airgun (10 in^3) and the sub-bottom profiler. Point A could not be reached due to ice encroachment, so after reaching OBH 1 (a 20 km approach) the vessel doubled-back and transited 5 km from OBH 1 back toward point B (yielding a 5 km departure). The airgun was fired every 20 m (about every 9 s).

TABLE 3.18. *Mt. Mitchell* SSV Track 9, with mitigation airgun and sub-bottom profiler, 13 Aug in Harrison Bay. Times are AKDT.

Event	Time	Latitude	Longitude	Range from OBH 1 (m)
Line 9 start (B)	20:31	70°43.566’ N	151°20.643’ W	20,100
CPA to OBH 1	23:18	70°40.830’ N	150°49.034’ W	14 (slant)
Line 9 end	00:02	70°41.625’ N	150°56.830’ W	5030

***Mt. Mitchell* SSV Track 13**: At the conclusion of Track 9, the seismic sources were turned off, and the *Mt. Mitchell* transited at 10 kts toward OBH 1 for retrieval (Fig. 3.18, Table 3.19). Ice presence prevented a direct approach to the OBH and the *Mt. Mitchell* could only transit at 10 kts at ranges between 1330 and 2100 m from the OBH. Only data for which the *Mt. Mitchell* travelled at 10 kts speed were analyzed for this track.

TABLE 3.19. *Mt. Mitchell* SSV Track 13, 14 Aug in Harrison Bay. Times are AKDT.

Event	Time	Latitude	Longitude	Range from OBH 1 (m)
Line 13 start	01:17	70°40.937’ N	150°52.264’ W	2100
CPA to OBH 1	01:23	70°40.302’ N	150°50.487’ W	1330
Line 13 end	01:23	70°40.232’ N	150°50.241’ W	1340

***High-Frequency Measurement 4:* Multibeam, single-beam and side-scan sonar**

***Mt. Mitchell* SSV Tracks 10–12**: The high-frequency measurement system was deployed over the side of the *Arctic Seal* as the *Mt. Mitchell* traversed three survey track lines while operating the multibeam, single-beam, and side-scan sonar. The survey lines extended 1 km on either side of the receiver, (Fig. 3.19), in 14 m water depth. The hydrophone was suspended at 7 m water depth. The high-frequency measurement system recorded approximately 1.5 h of data. Table 3.20 shows the start, and end locations of each SSV track line and the mean location of the hydrophone receiver. The source-receiver distance at the CPAs for Tracks 10–12 were 41, 199, and 380 m respectively.

TABLE 3.20. *Mt. Mitchell* SSV Tracks 10–12 with multibeam, single-beam, and side-scan sonar, 15 Sep at Mauya Prospect. Times are AKDT.

Event	Time	Latitude	Longitude	Range from hydrophone (m)
Line 10 start	13:28	70°38.170' N	149°59.294' W	1100
CPA to hydrophone	13:36	70°38.214' N	150°01.058' W	41
Line 10 end	13:45	70°38.226' N	150°02.733' W	1030
Line 11 start	14:07	70°38.140' N	150°02.826' W	1100
CPA to hydrophone	14:16	70°38.217' N	150°01.057' W	199
Line 11 end	14:24	70°38.083' N	149°59.388' W	1060
Line 12 start	14:35	70°37.980' N	149°59.321' W	1170
CPA to hydrophone	14:44	70°38.216' N	150°01.072' W	380
Line 12 end	14:52	70°38.037' N	150°02.759' W	1090

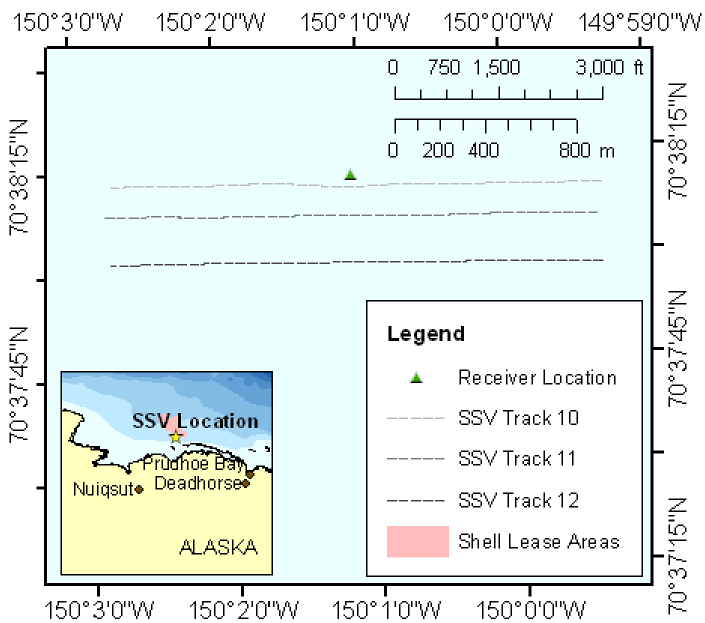


FIGURE 3.19. *Mt. Mitchell* SSV Tracks 10–12 with multibeam, single-beam, and side-scan sonar, 15 Sep at Mauya Prospect.

Data Analysis

Noise Metrics

Underwater sound amplitude is measured in decibels (dB) relative to a fixed reference pressure of 1 µPa. Several sound level metrics are commonly used to evaluate the loudness or effects of impulsive noise. The primary sound level metrics of importance here are peak sound pressure level (peak SPL, L_{pk}), 90% rms sound pressure level (rms SPL, L_{p90}), and sound exposure level (SEL, L_E).

Peak SPL (dB re 1 µPa) is the maximum instantaneous sound pressure level attained by an impulse, $p(t)$:

$$L_{pk} = 20\log_{10}\left\{\max\left(\left|p(t)\right|\right)\right\} \qquad \text{Equation 1}$$

The 90% rms SPL (dB re 1 µPa) is the root-mean-square pressure level over a time window referred to as T_{90}:

$$L_{p90} = 10\log_{10}\left(\frac{1}{T_{90}}\int_{T_{90}} p^2(t)\,dt\right) \qquad \text{Equation 2}$$

where T_{90} is the time interval containing the central 90% (from 5% to 95% of the total) of the cumulative square pressure of the pulse.

The SEL (dB re 1 µPa^2·s) is the time integral of the square pressure over the fixed time window containing the entire pulse, T_{100}:

$$L_E = 10\log_{10}\left(\int_{T_{100}} p^2(t)\,dt\right) \qquad \text{Equation 3}$$

To compute SPL and SEL of pulses in the presence of high levels of background noise, Equations 2 and 3 are modified to subtract the background noise contribution from the pulse energy:

$$L_{p90} = 10\log_{10}\left(\frac{1}{T_{90}}\int_{T_{90}} p^2(t)\,dt - \overline{n^2}\right) \qquad \text{Equation 4}$$

$$L_E = 10\log_{10}\left(\int_{T_{100}} p^2(t)\,dt - \overline{n^2}T_{100}\right) \qquad \text{Equation 5}$$

where $\overline{n^2}$ is the mean square pressure of the background noise, computed by averaging the squared pressure over a time segment of the acoustic recording preceding the pulse.

Because the 90% rms SPL and SEL are both computed from the integral of square pressure, these metrics are related by a simple expression, which depends only on the duration of the 90% integration time window T_{90}:

$$L_E = L_{p90} + 10\log_{10}\left(T_{90}\right) + 0.458 \qquad \text{Equation 6}$$

where the 0.458 dB factor accounts for the rms level containing 90% of the total energy from the per-pulse SEL.

Per-Shot Pulse Levels

The loudness or magnitude of each recorded pulse from airgun, sub-bottom profiler and sonar sources was quantified by computing the three noise metrics described above: peak SPL, 90% rms SPL, and SEL. Each pulse was analyzed as follows:

1. Convert digital recording units to micropascals (µPa) by applying hydrophone sensitivity, analogue circuit frequency response, and digital conversion gain.
2. For sources greater than 1 kHz, apply high-pass or band-pass filters to remove vessel and flow-noise outside the sonar's bandwidth. The specific filter characteristics are indicated in the methods sections for the respective sources.
3. Determine start time of the impulsive pressure signal with an automatic power-threshold detector.
4. Compute peak SPL (symbol L_{pk}) according to Equation 1.
5. Compute cumulative square pressure over the duration of the pulse.
6. Determine the 90% time window length (T_{90}) and compute 90% rms SPL (symbol L_{p90}) according to Equation 2.
7. Compute SEL (symbol L_E) according to Equation 3 over the duration of the pulse.

Continuous Sound Levels

The continuous (non-impulsive) noise produced by the survey vessels was quantified by computing rms SPLs over consecutive 1-s time windows by employing Equation 2 with $T = 1$ s.

Percentile spectral levels were calculated for the *Ocean Pioneer* in DP mode and for the Vibracore. For each recording, 1-second sound spectra were computed from the acoustic data using 1 a nalysis windows (48,000 samples) with 50% overlap. The time-domain data were shaded using a normalized Hamming window to minimize spectral leakage. Sound power spectral levels were computed with 1 Hz frequency resolution up to the Nyquist frequency (24 kHz). The statistical distribution of the noise was calculated by constructing a histogram of the 1-s spectral values. A bin width of 0.1 dB was used for the noise histograms. The histogram distributions were used to calculate the 5th, 25th, 50th, 75th, and 95th percentile noise spectral levels (the *n*th percentile level is defined as the sound level that was exceeded *n*% of the time, in compliance with ISO standard 1996-1:1982). Source levels were estimated by back-propagating the 5th percentile levels, based on 20log*R* (spherical) spreading.

Sound Level versus Range

The noise metrics computed for each source are presented as a function of source-receiver range. To estimate the distance to sound level thresholds and the source level for each monitored sound source, the 90% rms SPL (L_{p90}) as a function of range (*R*, in meters) were fit with an empirical transmission loss function of the form:

$$L_{p90} = SL - n \log R - \alpha R, \text{ or} \qquad \text{Equation 7}$$

$$L_{p90} = SL - n \log R \qquad \text{Equation 8}$$

where SL is the source level term (dB re 1 µPa @ 1 m), *n* is the geometric spreading loss coefficient, and α is the absorption loss coefficient, and these coefficients are determined by least-squares regression. Equation 7 is used if absorptive losses are present or if apparent curvature exists in the received level versus log(R) data trend, whereas Equation 8 is used if no significant absorptive losses exist.

Sound is attenuated as it propagates through seawater due to chemical relaxation processes. This attenuation increases with frequency and is thus a significant factor for high-frequency sources, such as side-scan and multibeam sonar. Received sound levels of the high frequency sources were not always detectable over sufficient ranges to yield reasonable fits of level-versus-range. In these cases we set α in Equation 7 to a fixed calculated value, which depends on the sound frequency, water temperature, pH, and salinity at the measurement site (Francois and Garrison 1982). We obtained water temperature and salinity values at the study sites either as in situ measurements from conductivity-temperature-depth (CTD) casts or as monthly means from the Generalized Digital Environmental Model database (Carnes 2009, Teague 1990), and averaged these values over depth. Absorption coefficients were calculated from these values at the center frequency of the source using the Francois and Garrison formula, assuming a pH level of 8.0.

To conservatively estimate the source level and range to SPL thresholds of 190 to 120 dB re 1 μPa, these best-fit functions were shifted upward (in dB) to exceed 90% of the rms SPL data points, yielding the 90th percentile fits. The distances to the SPL thresholds and the source level terms derived from the curve fits are tabulated for each source, for both the best fit and 90th percentile fit. Source levels were also estimated by back-propagation from the nearest measurement assuming spherical spreading (20 log$R$), and, for high-frequency sources, also including a fixed absorption loss term (αR).

Spectral Analysis

The broadband frequency content of each source was presented in three formats: (i) spectrogram, (ii) spectral density over a specified time window, and (iii) 1/3-octave band levels.

For 1/3-octave band analysis of impulsive sources, the sound data were band-pass filtered into several adjacent frequency bins, and the SEL of each bin computed. The acoustics community has adopted standard third-octave frequencies (more precisely these are 10th decade band frequencies) (ISO R 266 and ANSI S1.6-1984) to facilitate comparisons between studies; the central frequency of the ith standard pass-band is:

$$f_{ci} = 10^{i/10}, \quad i = 1, 2, 3, \ldots \qquad \text{Equation 9}$$

The bandwidth of a single 1/3-octave band is ~23% of the central frequency of the band. Third-octave band analysis was applied to both continuous and impulsive noise sources.

Results

Results are presented separately for the Geotechnical Development and Shallow Hazards Programs. They are grouped by measurement location and then sound source. For sites at which conductivity-temperature-depth (CTD) profiles were taken, the measured profiles and resulting sound speed profile are presented at the start of the section for that location.

Geotechnical Development Program

<u>*Burger Prospect, Chukchi Sea*</u>

Sound Speed Profile

Salinity and sound speed as a function of depth were calculated by C&C Technologies with a conductivity-temperature-depth (CTD) profiler at the Burger prospect on 6 and 7 Sep 2010. CTD casts were performed before deploying the OBH system (Fig. 3.20), after measuring the sub-bottom profiler (Fig. 3.21), and before measuring the AUV sonar sources (Fig. 3.22).

The sound speed results show a well-mixed higher-speed surface layer over a lower-speed layer. The higher-speed surface layer speeds range from 1465 to 1470 m/s and the lower-speed deeper layer speeds range from 1442 to 1450 m/s. The transition depth decreases over the course of the measurements from 25 to 10 m. All three sound speed profiles exhibit a downward-refracting shape due to warmer water at the surface. Downward refracting sound speed profiles tend to increase acoustic propagation loss with range due to increased bottom interactions.

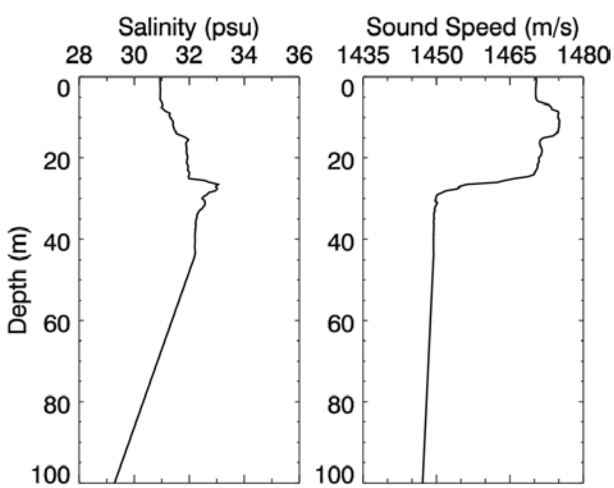


FIGURE 3.20. Salinity (left) and sound speed (right) profiles from CTD cast before deploying the OBHs for the sub-bottom profiler measurements at 16:23 h, 6 Sep at 71°05.361' N, 163°32.340' W.

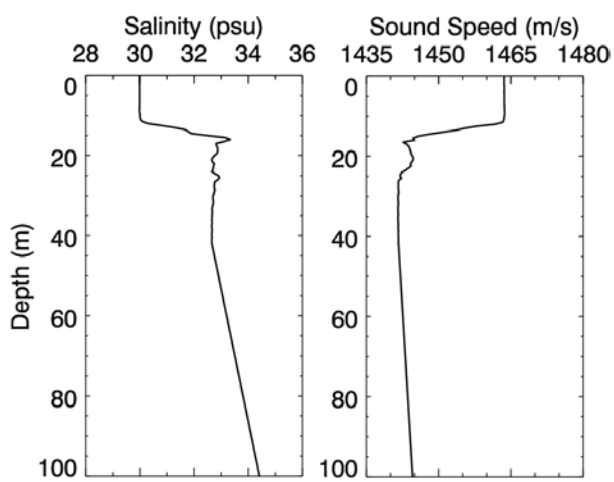


FIGURE 3.21. Salinity (left) and sound speed (right) profiles from CTD cast after the OP sub-bottom profiler measurement at 22:32 h, 6 Sep at 71°22.131' N, 163°03.641' W.

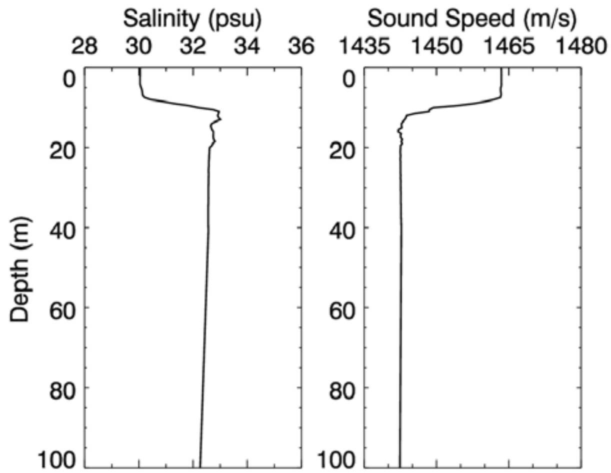


FIGURE 3.22. Salinity (left) and sound speed (right) profiles from CTD cast before the AUV sonar measurements at 14:58 h, 7 Sep at 71°22.081' N, 163°10.690' W.

R/V Ocean Pioneer Self-Noise, Transiting

Vessel noise produced by the *Ocean Pioneer* transiting at 10 kts was measured during OBH Deployment 1 on 5 Aug along SSV Track 1. At the closest points of approach, the *Ocean Pioneer* was 12 m and 25 m away from OBHs S-02 and S-03, respectively, in 46 m water depth.

Continuous sound levels were analyzed in 1-s time windows over the SSV Track. Fig. 3.23 shows rms SPL versus time from each OBH. The peaks indicate the time of CPA, relative to the SSV Track start time.

Fig. 3.24 shows rms SPL versus range from both OBHs in the forward and aft directions. Distances to sound level thresholds (Table 3.21) were determined from transmission loss curve fits to these data using a function in the form of Equation 8. Spectrograms of 5 min surrounding each CPA are shown in Fig. 3.25. Mean power spectral density (PSD) was calculated from 10 s centered on each CPA and is shown in Fig. 3.26.

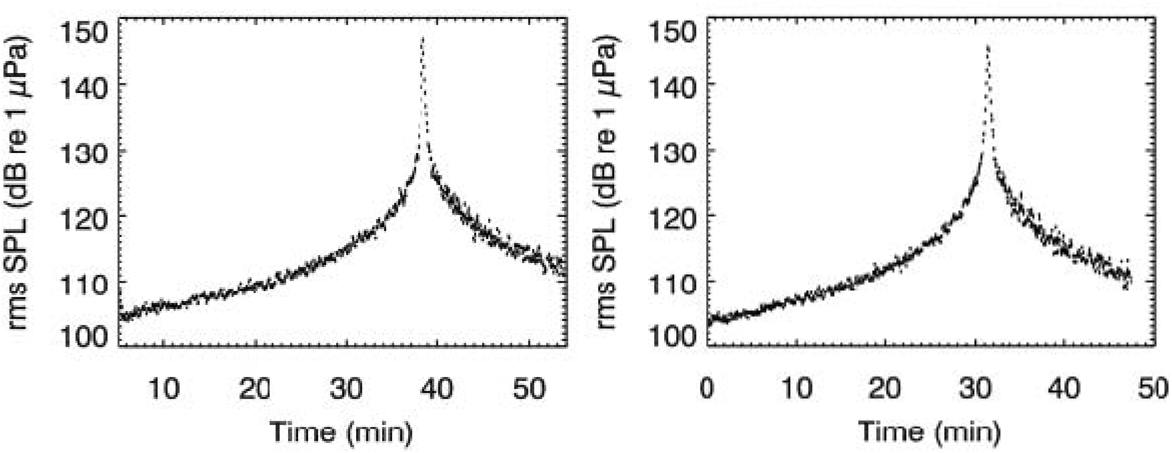


FIGURE 3.23. *Ocean Pioneer* rms SPL versus time, in 1-s intervals while transiting at 10 kts measured by OBH S-02 with a 12 m CPA (left) and S-03 with a 25 m CPA (right).

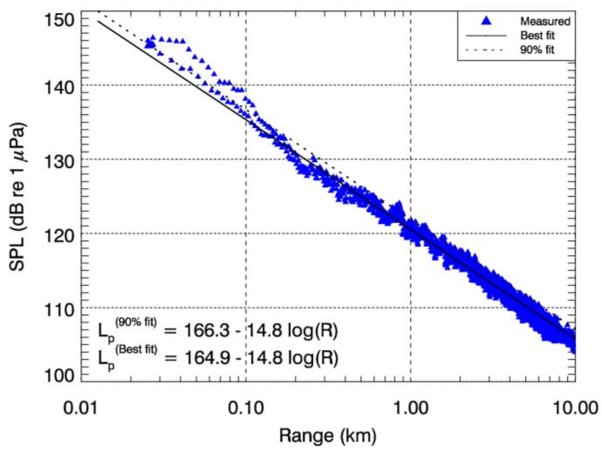


FIGURE 3.24. *Ocean Pioneer* rms SPL versus range while transiting at 10 kts in fore (left) and aft (right) directions, including data from both OBHs. Solid line is best fit of the empirical function to L_{p90} values. Dashed line is the best-fit shifted to exceed 90% of the L_{p90} values (90th percentile fit).

TABLE 3.21. Distance to rms SPL thresholds for the *Ocean Pioneer* transiting at 10 kts in the forward and aft directions.

rms SPL threshold (dB re 1 μPa)	Forward of *Ocean Pioneer*		Aft of *Ocean Pioneer*	
	Best-fit	90th percentile-fit	Best-fit	90th percentile-fit
160	2	3	2	2
150	10	13	9	11
140	48	60	47	58
130	230	280	240	300
120	1100	1300	1200	1600
SL term (dB re 1 μPa @ 1 m)	164.9	166.3	163.3	164.7

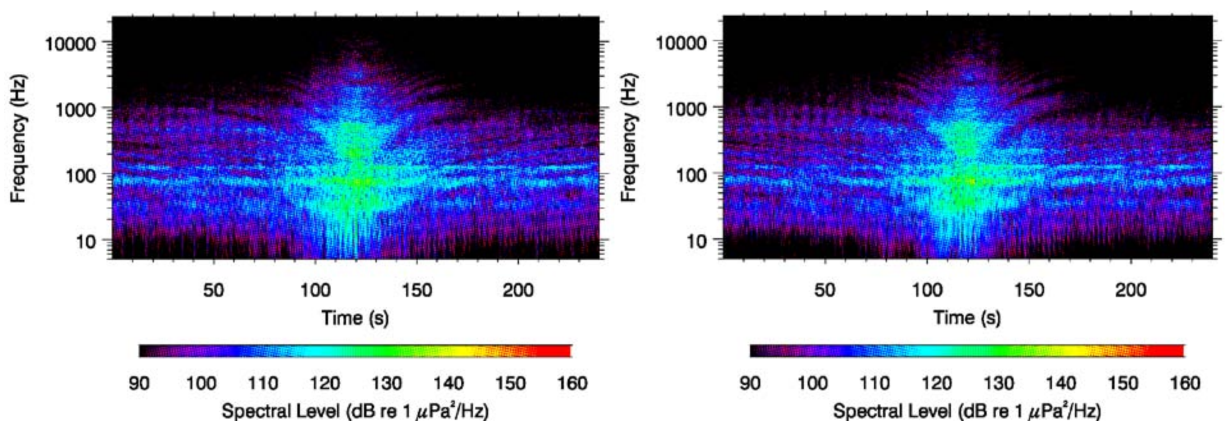
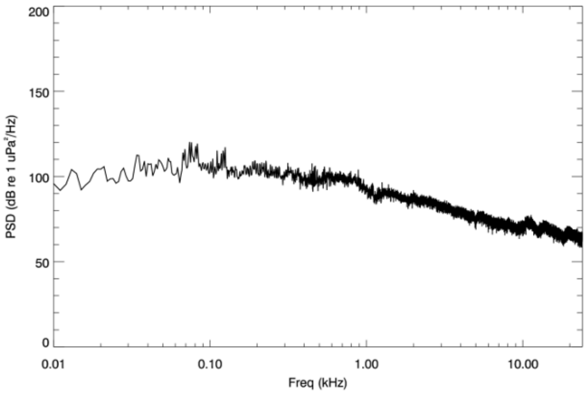


FIGURE 3.25. Spectrograms of the *Ocean Pioneer* transiting at 10 kts at 12.4 m (left) and 24.8 m (right) distance. 8192-pt FFT, 48 kHz sample rate, Hanning window, 1024-pt step size.



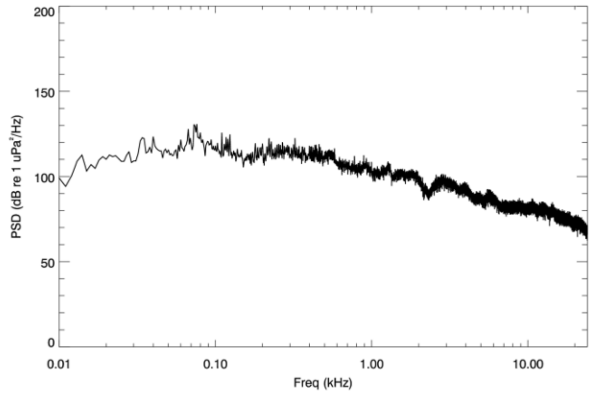


FIGURE 3.26. Average power spectral density (PSD) of the *Ocean Pioneer* transiting at 10 kts from average of 10 one second Hanning-windowed spectra at 12 m (left) and at 25 m (right) distance.

R/V Ocean Pioneer Self-Noise, in DP Mode

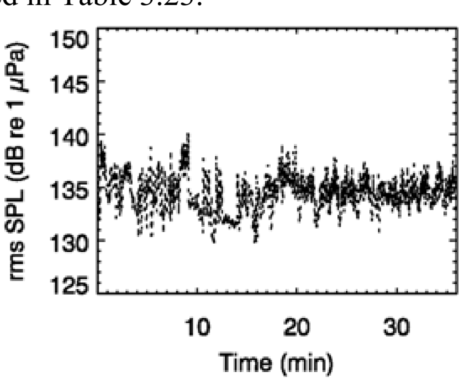
Noise produced by the *R/V Ocean Pioneer* in Dynamic Positioning (DP) mode was measured during OBH Deployment 1 on 6 Aug at 46 m water depth, during deployment of the Vibracore. The vessel retained a constant slant range of 74 m from OBH S-03 and 207 m from OBH S-02, referenced to the location of the vessel's aft thruster.

Sound levels were processed in 1-s windows over the duration of the DP test. Broadband rms SPL over time is shown in Fig. 3.27. Spectrograms of 5 min extracts from the recordings of the *Ocean Pioneer* in DP mode are shown in Fig. 3.28. Fig. 3.29 shows percentile spectrum levels of the *Ocean Pioneer*'s DP recordings prior to the deployment of the Vibracore. The 5th and 50th percentile received levels are shown in Table 3.22.

The source level of the *Ocean Pioneer* in DP was estimated by back-propagation, using the acoustic spreading term from the *Ocean Pioneer* transit SSV Track 1 on 5 Aug from the forward direction measurement. The 5th percentile SPL results at the two stations were independently back-propagated and averaged, giving a source level of 175.9 dB re 1 μPa @ 1 m. The resulting equation describing the received 5th percentile broadband rms SPL (RL) of the *Ocean Pioneer* in DP is:

$$\mathrm{RL} = 175.9 - 14.9\log_{10}(r) \qquad \text{Equation 10}$$

where r is slant range in meters. This formula was used to derive the sound level threshold radii summarized in Table 3.23.



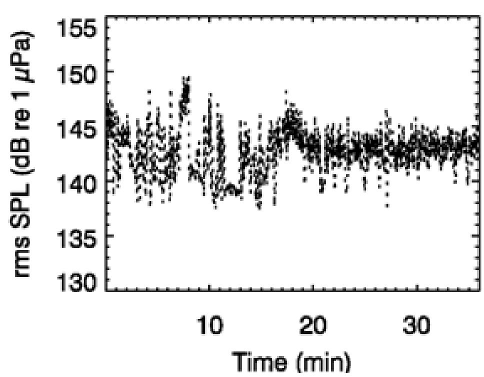


FIGURE 3.27. *Ocean Pioneer* in DP broadband rms SPL versus time measured at 207 m (left) and 74 m (right) slant range.

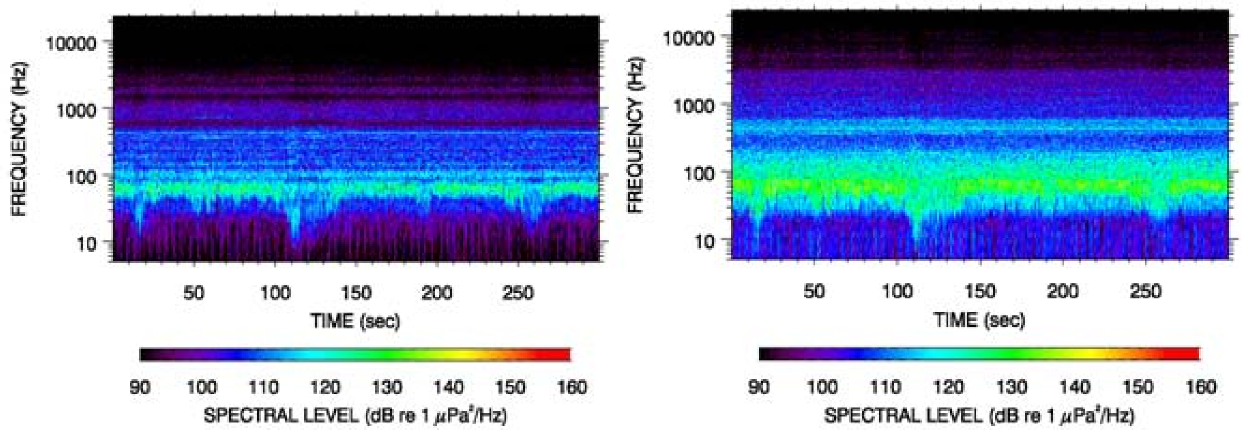


FIGURE 3.28. Spectrogram of *Ocean Pioneer* in DP measured at 207 m (left), and 74 m (right) slant range. 8192-pt FFT, 48-kHz sample rate, Hanning window, 1024-pt step size.

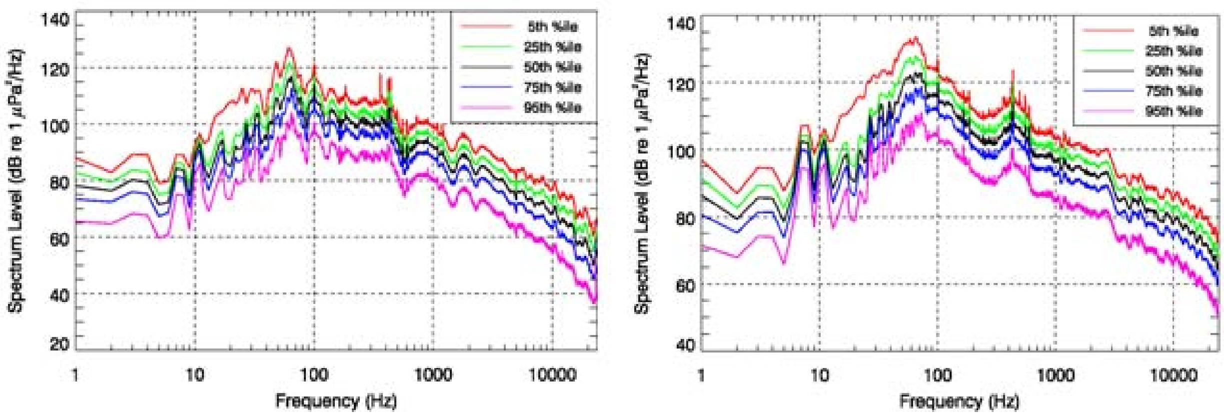


FIGURE 3.29. Percentile spectra of *Ocean Pioneer* in DP measured at 207 m (left) and 74 m (right) slant range, based on 1-s (48,000-pt) FFTs, 48-kHz sample rate, Hamming window, 50% overlap.

TABLE 3.22. Median (50th percentile) and 5th percentile broadband rms SPL for the *Ocean Pioneer* in DP over 1-s time windows, recorded at each OBH.

OBH	Range from ship (m)	Slant range from ship (m)	50th percentile SPL (dB re 1 μPa)	5th percentile SPL (dB re 1 μPa)
S-03	58	74	139.5	148.8
S-02	202	207	131.4	140.5

TABLE 3.23. Distance to sound level thresholds for the *Ocean Pioneer* in DP obtained by scaling the 5th percentile received SPL using the propagation loss function from *Ocean Pioneer* transit (Equation 10).

rms SPL threshold (dB re 1 µPa)	Distance (m)
160	12
150	55
140	260
130	1200
120	5600
SL (dB re 1 µPa @ 1 m):	175.9

Vibracore, Vibratory Coring System

Noise produced by the Vibracore system was measured on OBHs S-02 and S-03 on 6 Aug in 46 m water depth as part of a dedicated DP mode and Vibracore test (OBH Deployment 1). The vessel remained at a constant slant range of 74 m from S-03 and 207 m from S-02, referenced to a point on the vessel within 10 m of the Vibracore. The Vibracore was operating as it was lowered, and sound levels peaked approximately 2 min into the deployment. However, sound levels then decreased and the vibrator ceased before it reached the seabed. This problem with the vibrator was attributed to hydrostatic pressure restricting the air flow through the pressure feed and exhaust lines. Despite this setback, the maximum sound levels recorded during this test are likely representative of the levels that would have occurred had the Vibracore operated properly while on the seabed.

Sound pressure time series produced by the Vibracore are shown on two timescales in Fig. 3.30: In the left plot, the gradual decrease in received sound level due to pressure line restrictions is evident. The right plot shows that pulses occurred at a rate of approximately 20 per second (one every 0.048 s on average). Vibracore pulses were observed to have a mean 90% rms duration of 14 ms.

The waveform and SEL spectral density of a single pulse is shown in Fig. 3.31 and the broadband SPL over the operational period, in Fig. 3.32.

Spectrograms of the Vibracore and vessel noise over time from each OBH are shown in Fig. 3.33. The striated spectral pattern of the Vibracore is an interference pattern caused by interaction of direct and surface reflected sound energy as the Vibracore was lowered through the water.

Fig. 3.34 shows spectrum density percentile levels of the Vibracore from immediately prior to start until end of operation. The 5th and 50th percentile received levels are shown in Table 3.24.

Third octave band levels were calculated by averaging sound levels (1-s windows) from 30 s of the peak period of Vibracore operation, and are shown in Fig. 3.35.

The estimated source level of the Vibracore was calculated using back-propagation, with the acoustic spreading term from the *Ocean Pioneer* traversing SSV Track 1 on 5 Aug. It is possible to use this equation due to the similarities in source frequencies. The 5th percentile SPL results at the two OBHs were independently back-propagated and averaged to give a source level of 187.4 dB re 1 µPa @ 1 m. Therefore, the equation describing the received 5th percentile broadband SPL (RL) of the Vibracore is:

$$\mathrm{RL} = 187.4 - 14.9\log_{10}(r) \qquad \text{Equation 11}$$

where *r* is slant range in meters. This formula was used to derive the sound level threshold radii summarized in Table 3.25.

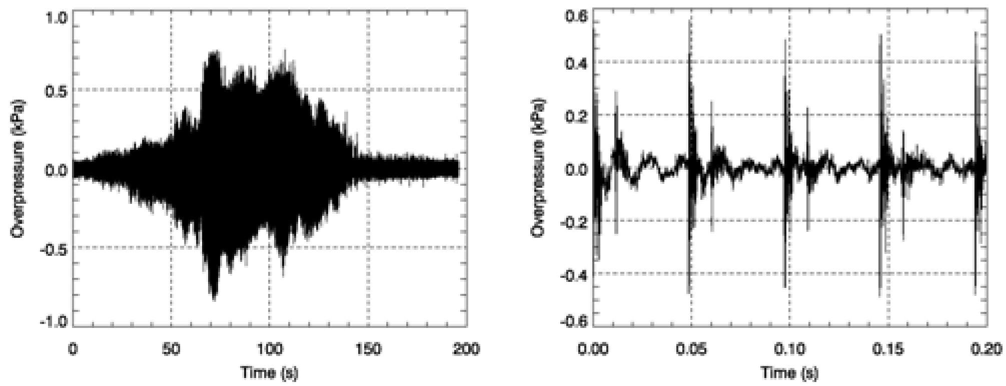


FIGURE 3.30. Vibracore sound pressure time series: full time period from when it entered the water to when it stopped operating (left), and 5 individual pulses (right), both measured at 74 m slant range.

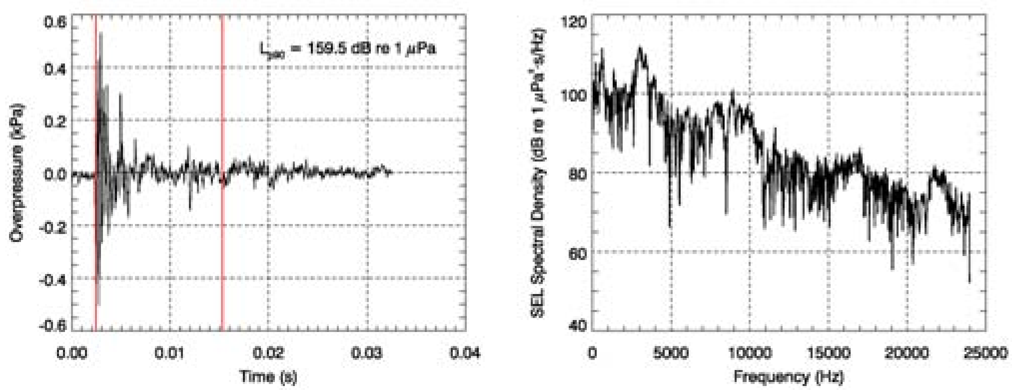


FIGURE 3.31. Waveform (left) and SEL spectral density over 40 ms (right) of a single Vibracore pulse at 74 m slant range.

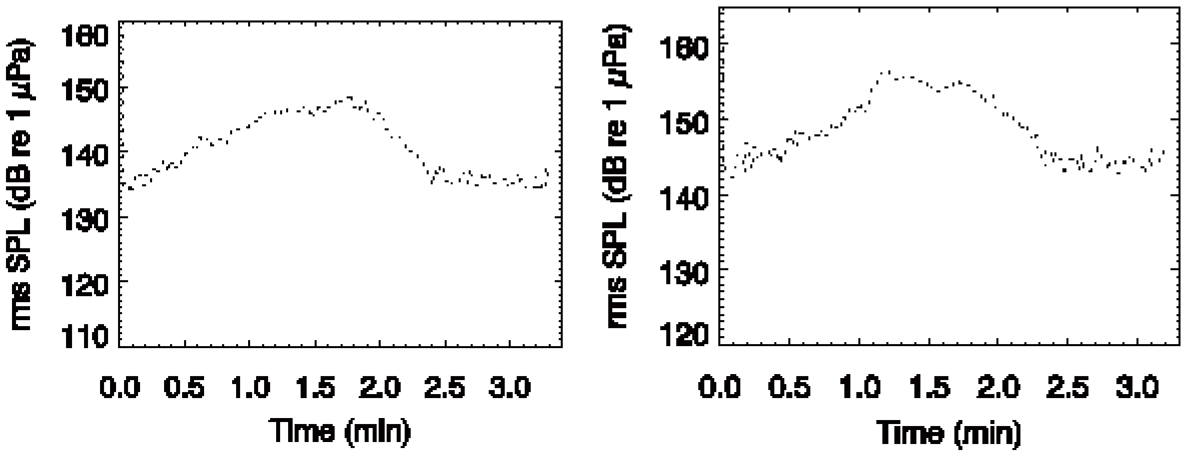


FIGURE 3.32. Vibracore and vessel broadband rms SPL over time measured at 207 m (left) and 74 m (right) slant range.

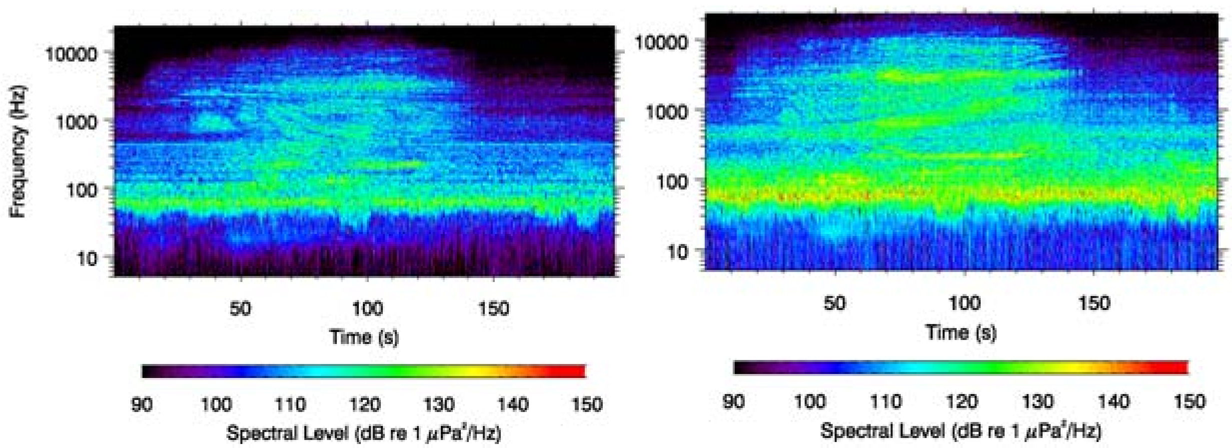


FIGURE 3.33. Spectrogram of Vibracore and vessel noise over time measured at 207 m (left) and 74 m (right) slant range. 8192-pt FFT, 48-kHz sample rate, Hanning window, 1024-pt step size.

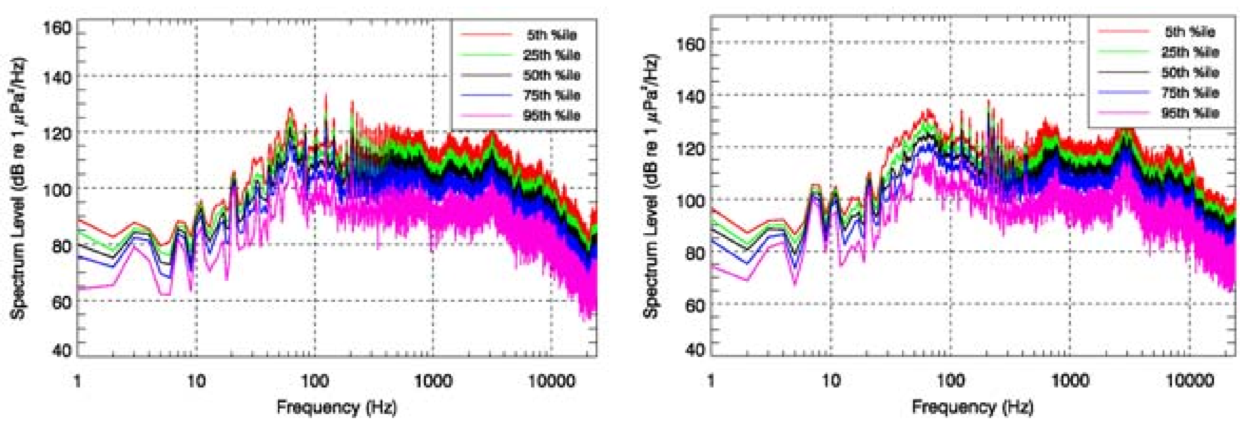


FIGURE 3.34. Percentile spectra of the Vibracore and vessel measured at 207 m (left) and 74 m (right) slant range. 1-s (48,000-pt) FFTs, Hamming window, 50% overlap.

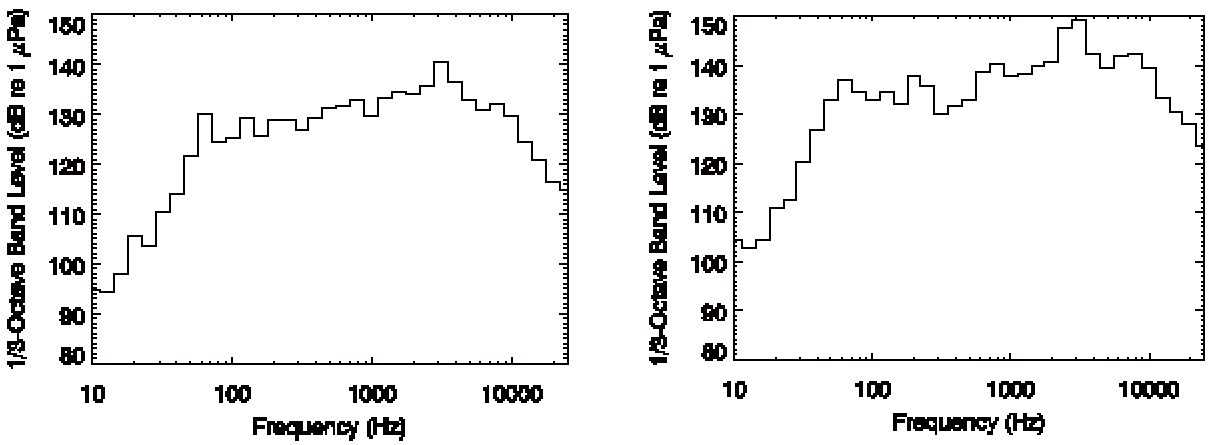


FIGURE 3.35. Vibracore average 1/3-octave band SPL of thirty 1-s windows measured at 207 m (left) and 74 m (right) slant range. The 30-s window for both plots corresponds to 75–105 s in Fig. 3.33.

TABLE 3.24. Median (50th percentile) and 5th percentile broadband rms SPL for the Vibracore and vessel over 1-s time windows, recorded at each OBH.

OBH	Range from ship (m)	Slant range from ship (m)	50th percentile SPL (dB re 1 μPa)	5th percentile SPL (dB re 1 μPa)
S-03	58	74	152.4	160.0
S-02	202	207	143.9	152.2

TABLE 3.25. Distance to sound level thresholds for the Vibracore obtained by scaling the 5th percentile received rms SPL using the propagation loss function from the *Ocean Pioneer* transit (Equation 11).

rms SPL threshold (dB re 1 μPa)	Distance (m)
170	15
160	69
150	320
140	1500
130	7100
120	30,000*
SL (dB re 1 μPa @ 1 m):	187.4

* Based on extrapolation using acoustic transmission loss function derived from Ocean Pioneer vessel transit to 10 km range only.

Sub-Bottom Profiler, Towfish

Underwater sound from the sub-bottom profiler towfish (EdgeTech 3100 SB-216S) was measured during OBH Deployment 2 as the profiler was towed by the *Ocean Pioneer* along SSV Track 2. The measurement was done 6 Sep as the profiler approached and departed the OBH. The OBH was deployed at the Burger prospect in 51 m water depth, with the hydrophone approximately 3 m above the seafloor. The profiler was towed at a nominal depth of 5 m and the CPA was at 46 m slant range.

Fig. 3.36 shows sound levels versus slant range for the sub-bottom profiler pulses. The pulses were band-pass filtered from 2 to 12 kHz to omit contributions from other noise sources. A curve of the form in Equation 8 was fit to the filtered data and the resulting distances to threshold levels are listed in Table 3.26. Sound levels at slant ranges less than 70 m are higher than the curve fits because at those ranges the OBH was in the main vertical beam of the sub-bottom profiler. Pulses beyond 1.5 km range were indistinguishable from background noise.

A spectrogram of three sub-bottom profiler pulses measured at approx. 50 m slant range (near CPA) is shown in Fig. 3.37. The pulse firing rate was approximately 300 ms with nominal pulse duration of 20 ms. The spectrogram shows an up-sweep frequency pattern from 3 to 11 kHz.

Fig. 3.38 shows a sub-bottom profiler pulse waveform and spectrum measured at approx. 50 m slant range (near CPA). A background spectrum is also shown for a 30 ms time period preceding the pulse. The waveform was high-pass filtered at 120 Hz and the spectra are shown at frequencies above 1 kHz. The pulse spectrum exceeds background levels at frequencies between 3.5 and 11 kHz, agreeing with the 3–12 kHz profiler setting used during the measurement.

Third-octave band levels were calculated for the 10 highest rms-amplitude pulses and of the background noise from 30 ms windows preceding those pulses. The band levels were averaged over all 10 windows and are shown in Fig. 3.39. Band levels are highest in the 8.2 kHz frequency band and exceed background levels in frequency bands centered between 3.2 and 13 kHz.

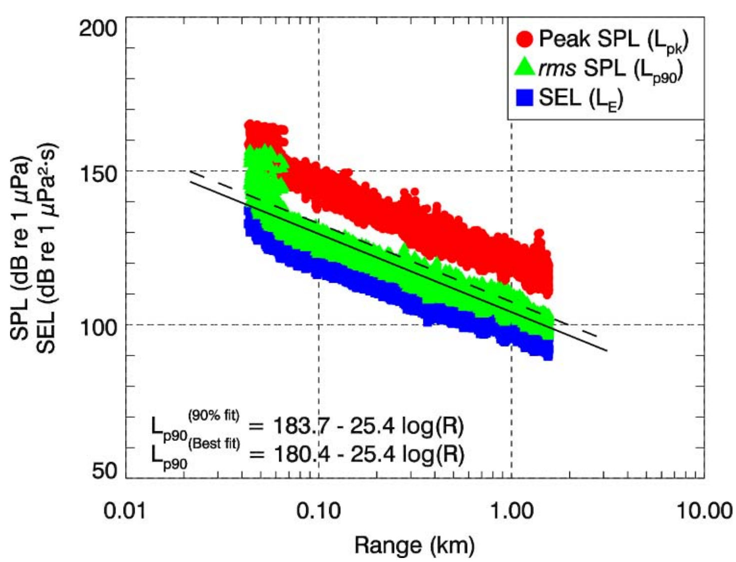


FIGURE 3.36. Sub-bottom profiler (EdgeTech 3100 SB-216S, SSV track 2) peak, 90% rms SPL and SEL versus slant range, 48 m measurement depth. Solid line is best fit of the empirical function to L_{p90} values. Dashed line is the best-fit shifted to exceed 90% of the L_{p90} values (90th percentile fit). The increase in sound levels within 70 m slant ranges due to the OBH being in the primary vertical beam of the profiler.

TABLE 3.26. Sub-bottom profiler (EdgeTech 3100 SB-216S, SSV track 2) source level terms and distances to sound level thresholds (48 m receiver depth) from least-squares fit (see Fig. 3.36).

rms SPL threshold (dB re 1 µPa)	Slant Range (m)	
	Best-fit	90^{th} percentile-fit
160	6*,[24]	9*,[31]
150	16*,[36]	21*,[49]
140	39*	52
130	96	130
120	240	320
110	590	790
100	1400	1900
SL term (dB re 1 µPa @ 1 m):	180.4	183.7

*Extrapolated values, less than minimum measurement slant range of 46 m.
[n] Based on a separate near-CPA analysis where the OBH is partly insonified by the main lobe of the projector, extrapolated if less than minimum measurement slant range of 46 m.

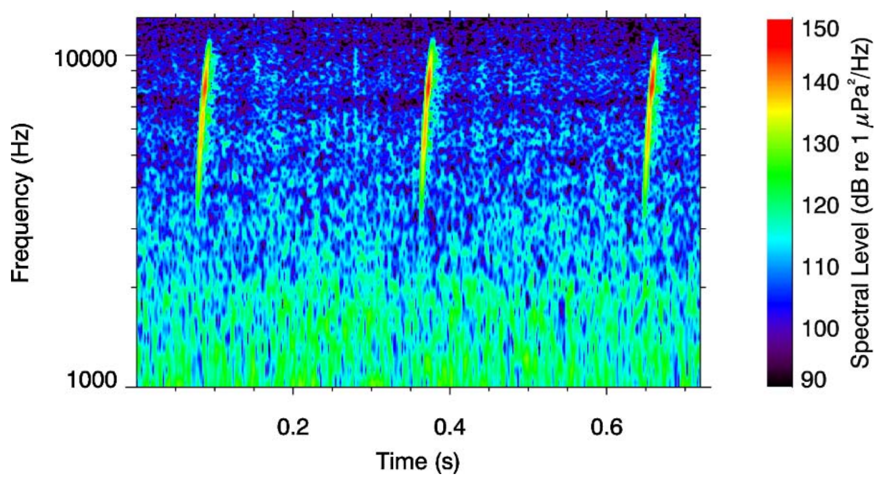


FIGURE 3.37: Spectrogram of three sub-bottom profiler (EdgeTech 3100 SB-216S, SSV track 2) pulses at approx. 50 m slant range (near CPA). 512-pt FFT, 48 kHz sample-rate, Hanning window, 64-pt step size.

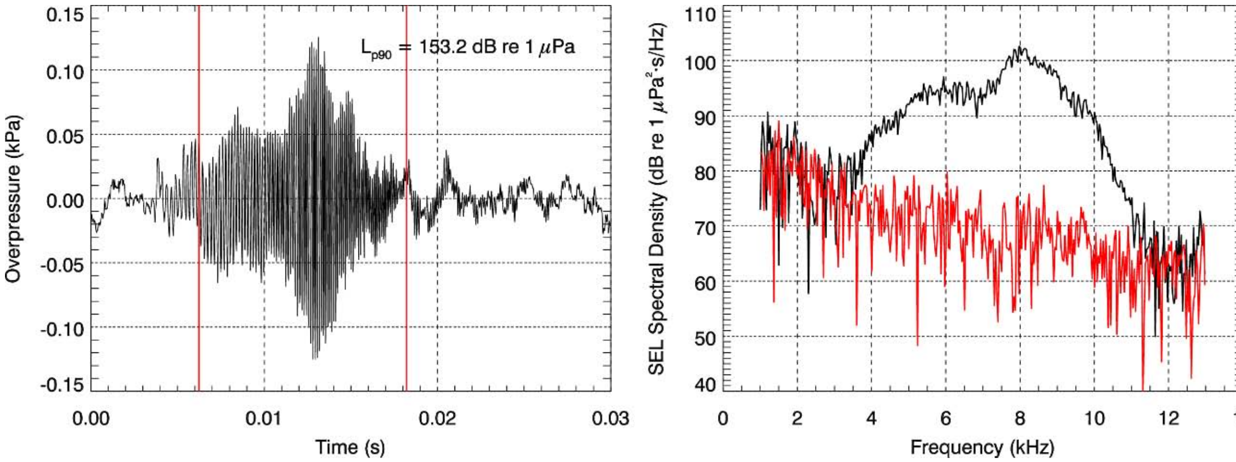


FIGURE 3.38. Sub-bottom profiler waveform (left) and SEL spectral density over 30 ms (right) of one pulse measured at 50 m slant range and 48 m receiver depth. The corresponding spectral density of background noise from the preceding 30 ms window is shown in red. Waveform was high-pass filtered at 120 Hz for display.

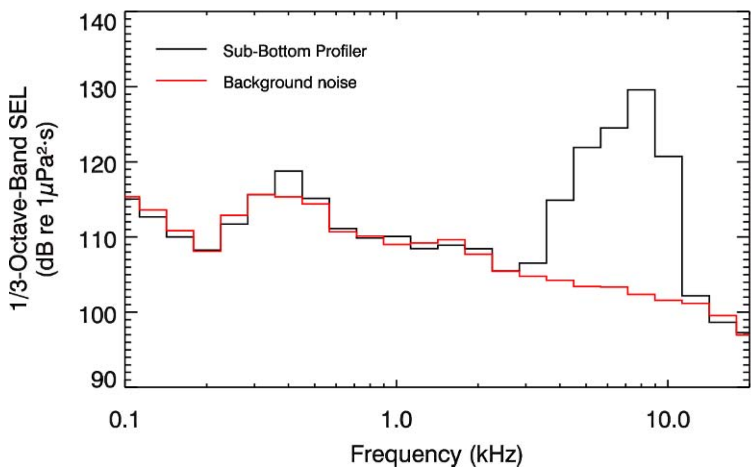


FIGURE 3.39. Sub-bottom profiler (EdgeTech 3100 SB-216S, SSV track 2) 1/3-octave band SEL over a 30-ms time window averaged over 10 of the highest rms-amplitude pulses measured at 50 m slant range and 48 m receiver depth. The corresponding average band levels of background noise from the 10 preceding 30 ms windows are shown in red.

Sub-Bottom Profiler, AUV

Underwater sound from the AUV sub-bottom profiler (EdgeTech 216) was recorded during High-Frequency Measurement 3 as the AUV was towed behind the *Ocean Pioneer*. The measurement was done at 6–10 m range on 8 Sep. The hydrophone was deployed from the *Ocean Pioneer's* aft-deck at a depth of 1–2 m. The AUV–hydrophone geometry was most stable during the first 2 min of the aft-deck recording, so measurements during this period were analyzed. It is unlikely that the hydrophone sampled in-beam levels of the sub-bottom profiler as it was positioned to the side of the AUV.

Received sound levels were calculated by band-pass filtering the pulses between 3 and 7 kHz to omit contributions from other sources. Background noise levels were computed from 24-ms time windows preceding each pulse and these were subtracted from the pulse levels to account for the contribution of background noise.

Source levels for the AUV sub-bottom profiler were estimated by back-propagating the average of the 10 highest rms-amplitude direct-path pulses, based on 20log*R* (spherical) spreading and 0.3 dB/km absorption loss[2] (which is negligible at this range). These levels are presented in Table 3.27. The source levels presented here represent out-of-beam levels.

Sound levels as a function of range were predicted using the measured source levels, from Table 3.27, and based on 20log*R* (spherical) geometric spreading loss and a 0.3 dB/km absorption loss coefficient. This transmission loss curve is over-plotted with the 10 highest rms-amplitude pulses Fig. 3.40. Distances to sound level thresholds based on the curve are presented in Table 3.28.

A spectrogram from 1 to 10 kHz of three AUV sub-bottom profiler pulses measured at 6–10 m range is shown in Fig. 3.41. The pulse repetition rate was approximately 4 per second with an approximate pulse duration of 10 ms. The spectrogram shows an up-sweep frequency pattern from 3 to 7 kHz.

Fig. 3.42 shows an AUV sub-bottom profiler pulse waveform, spectrum, and background spectrum measured at 6–10 m range. The waveform was band-pass filtered from 1 to 50 kHz for display. The pulse spectrum exceeds background levels at frequencies between 3.5 and 6 kHz, agreeing with the 3–7 kHz profiler setting used during the measurement.

Fig. 3.43 shows 1/3-octave band levels of the average of the 10 highest rms SPL pulses and of the background noise from 30 ms windows preceding the pulses. The band levels are highest in the bands centered at 4 and 5 kHz, and exceed background levels in frequency bands centered between 3.2 and 6.3 kHz. Again, these levels are representative of out-of-beam measurements.

TABLE 3.27. AUV sub-bottom profiler (EdgeTech 216) average received sound levels of ten 3–7-kHz pulses, measured at 6–10 m range and 1–2 m depth, and source levels (SL) derived by 20log*R* back-propagation with an absorption coefficient of 0.3 dB/km.

	Range (m)	Peak SPL (dB re 1 μPa)	rms SPL (dB re 1 μPa)	SEL (dB re 1 $\mu Pa^2 \cdot s$)
Mean received level	6-10	155.7	147.6	126.9
Lower Limit SL	1	171.3	163.1	142.5
Upper Limit SL	1	175.7	167.6	146.9

[2] Absorption loss at 5 kHz calculated based on GDEM monthly mean temperature for Sep at the measurement location (1.1°C, Carnes 2009, Teague et al. 1990), averaged over depth, and the mean salinity measured in situ (31.99 ppt, FIGURE 3.20 to FIGURE 3.22).

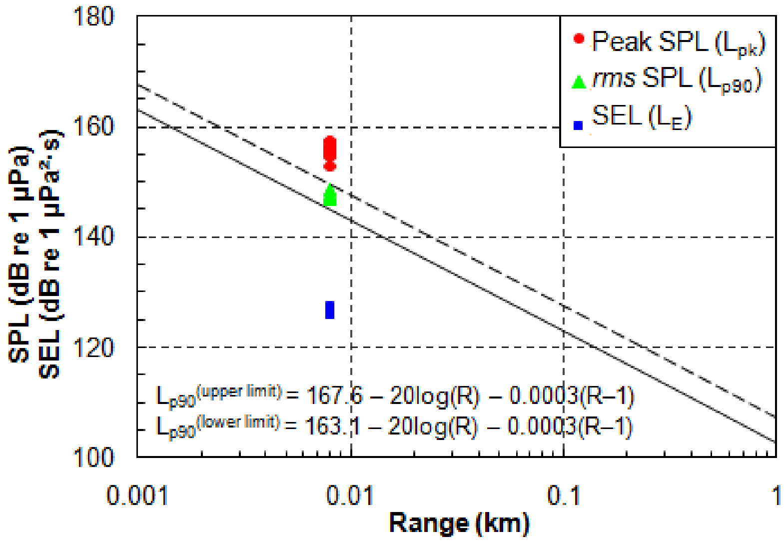


FIGURE 3.40. AUV sub-bottom profiler (EdgeTech 216) peak, 90% rms SPL and SEL versus range, at 1-2 m depth. Solid line is best fit of the empirical function to L_{p90} values. Dashed line is the best-fit shifted to exceed 90% of the L_{p90} values (90th percentile fit). Did not sample in-beam levels.

TABLE 3.28. Sub-bottom profiler (EdgeTech 216) source level terms and distances to sound level thresholds (1–2 m receiver depth) predicted from upper and lower limit source levels given in Table 3.27 assuming 20log*R* spreading and an a bsorption coefficient of 0.3 dB/km (see Fig. 3.40).

rms SPL threshold (dB re 1 μPa)	Distance (m)
190	-
180	-
170	-
160	2–3
150	5–8
140	15–24
130	45–75
120	140–240
SL term (dB re 1 μPa @ 1 m):	163.1–167.6

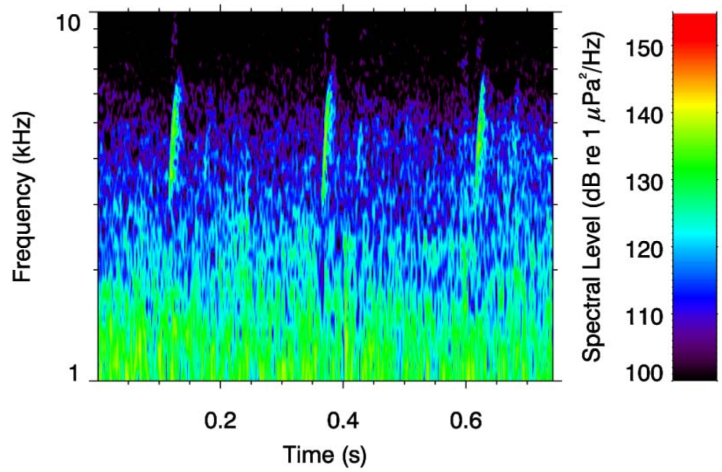


FIGURE 3.41: Spectrogram of three AUV sub-bottom profiler (EdgeTech 216) pulses at 6-10 m slant range. 8192-pt FFT, 1 MHz sample-rate, Hanning window, 1024-pt step size. Did not sample in-beam levels.

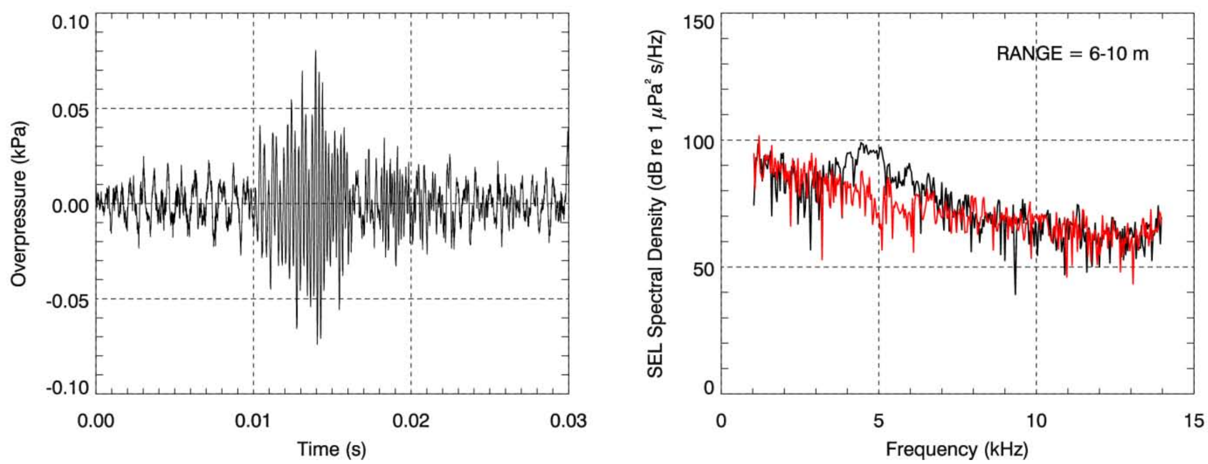


FIGURE 3.42. AUV sub-bottom profiler (EdgeTech 216) waveform (left) and SEL spectral density over 30 ms (right) of one pulse measured at 6–10 m range and 1–2 m receiver depth. The corresponding spectral density of background noise from the preceding 30 ms window is shown in red. Waveform was band-pass filtered from 1-50 kHz for display. Did not sample in-beam levels.

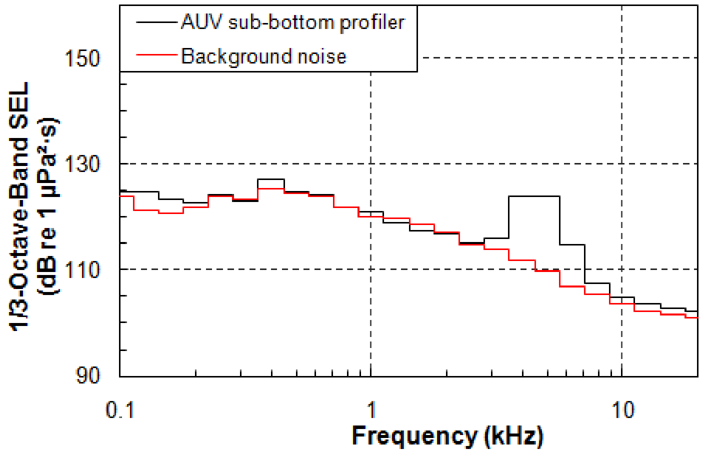


FIGURE 3.43. AUV sub-bottom profiler (EdgeTech 216) 1/3-octave band SEL over a 30-ms time window averaged over 10 of the highest rms-amplitude pulses measured at 6–10 m slant range and 1–2 m receiver depth. The corresponding average band levels of background noise from the 10 preceding 30 ms windows are shown in red. Did not sample in-beam levels.

Multibeam Sonar, Vessel-Mounted

The multibeam sonar (Kongsberg EM 3002), pole-mounted to the *Ocean Pioneer*, was measured during High-Frequency Measurement 1. Sound levels were recorded for 2 min on 6 Sep at a source-receiver range of 14 m. The hydrophone was deployed over the opposite side of the vessel at a depth of 6 m. While we tried to position the hydrophone at right-angles to the source transducer, we are not certain the hydrophone consistently sampled the in-beam sound levels. However, the recordings characterize the frequency content of these broadcast sonar pulses.

The detected sonar pulses were band-pass filtered from 287.5–312.5 kHz to remove non-acoustic noise and vessel sounds prior to computing received sound levels. Only direct-path pulses were included in source level analysis, and were therefore separated from bottom-reflected pulses based on rms pulse length. Resultant sound levels for direct-path and bottom-reflected pulses are presented in Fig. 3.44. The large variation in direct-path received levels is almost certainly due to the hydrophone entering and exiting the beam of the sonar.

Source levels for the pole-mounted multibeam sonar were estimated by back-propagating the average of the 10 highest rms-amplitude direct-path pulses, based on 20log*R* (spherical) spreading and 62.5 dB/km absorption loss [3]. These levels are presented in Table 3.29. The source levels presented here may not represent in-beam levels as discussed above.

Sound levels as a function of range were predicted using the measured source levels, from Table 3.29, and based 20log*R* (spherical) geometric spreading loss and a 62.5 dB/km absorption loss coefficient. This transmission loss curve is over-plotted with the 10 highest rms-amplitude pulses in Fig. 3.45. Distances to sound level thresholds based on the curve are presented in Table 3.30.

A spectrogram of four multibeam sonar pulses (un-filtered) is shown in Fig. 3.46 The bottom reflected signals are clearly visible and separated in time from the direct-path signals. The mean duration

[3] Absorption loss at 300 kHz calculated based on GDEM monthly mean temperature for Sep at the measurement location and the mean salinity measured in situ (31.99 ppt, Figs. 3.20 to 3.22)

for the 10 highest rms-amplitude direct-path pulses is 150 µs, and for the 10 highest rms-amplitude bottom reflections it is 23 ms. The waveform and SEL spectral density of a single direct-path pulse are shown in Fig. 3.47. The pulses are centered at a frequency of 300 kHz, with a bandwidth of approximately 10 kHz. There are no observed frequency side-lobes. Pulses occurred at a repetition rate of 1 every 165 ms (approximately 6 per second).

Un-filtered third-octave band levels were calculated from the average spectra from 10 direct-path pulses, each contained within a 1.5 ms window; background noise spectra from the average of 1.5 ms windows immediately preceding each pulse window are plotted concurrently in Fig. 3.48. Frequency components from the multibeam sonar are only visible in the band centered at 316.2 kHz.

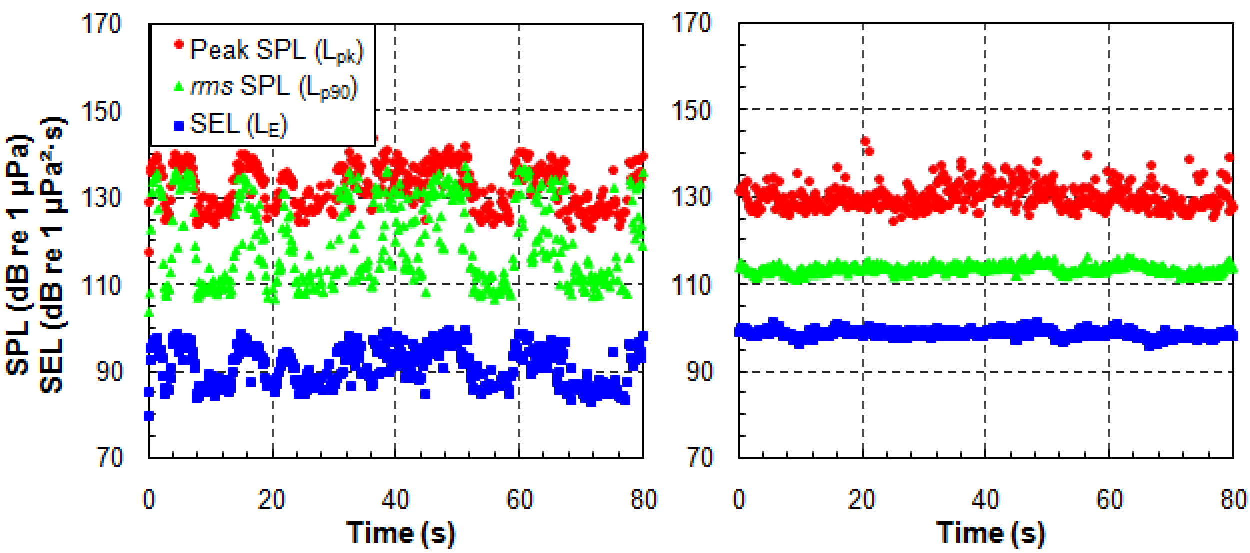


FIGURE 3.44. Multibeam sonar (Kongsberg EM 3002) 300-kHz pulse peak SPL, 90% rms SPL, and SEL over time measured at 14 m range and 6 m receiver depth. Direct-path (left) and bottom-reflected (right) pulses are shown separately.

TABLE 3.29. Multibeam sonar (Kongsberg EM 3002) average received sound levels of ten 300-kHz pulses, measured at 14 m range and 6 m depth, and source levels (SL) derived by 20log*R* back-propagation with an absorption coefficient of 62.5 dB/km.

	Range (m)	Peak SPL (dB re 1 µPa)	rms SPL (dB re 1 µPa)	SEL (dB re 1 µPa²·s)
Mean received level	14	142.1	137.9	100.1
Back-propagated SL	1	165.9	161.6	123.9

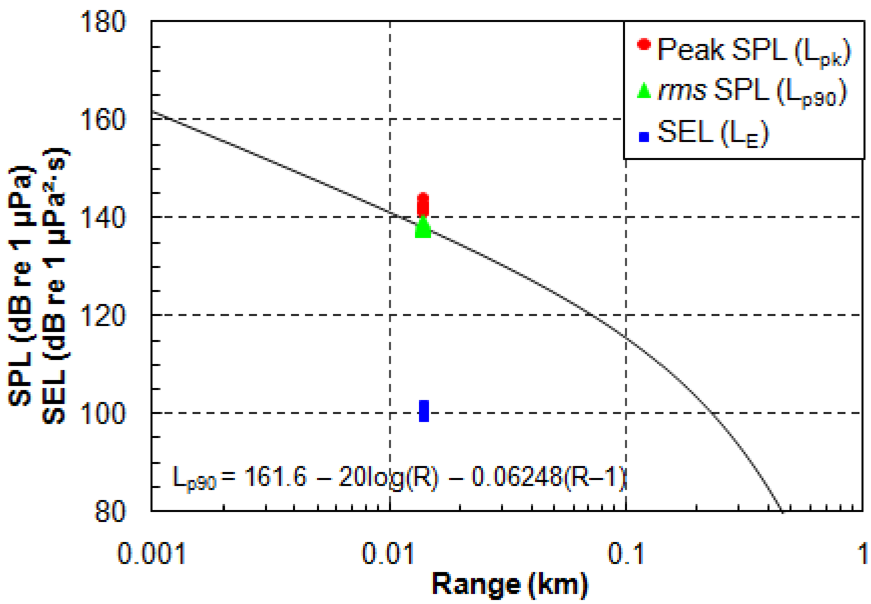


FIGURE 3.45. Multibeam sonar (Kongsberg EM 3002) 300-kHz pulse peak SPL, 90% rms SPL, and SEL of the 10 highest rms-amplitude pulses, measured at 14 m range and 6 m receiver depth, and sound levels as a function of range predicted from the back-propagated source levels given in Table 3.29 assuming 20log*R* spreading and an absorption coefficient of 62.5 dB/km.

TABLE 3.30. Multibeam sonar (Kongsberg EM 3002) 300-kHz pulse source levels and distances to sound level thresholds (6 m receiver depth) predicted from back-propagated source levels given in Table 3.29 assuming 20log*R* spreading and an absorption coefficient of 62.5 dB/km (see Fig. 3.45).

rms SPL threshold (dB re 1 µPa)	Distance (m)
160	1
150	4
140	11
130	31
120	72
SL (dB re 1 µPa @ 1 m):	161.6

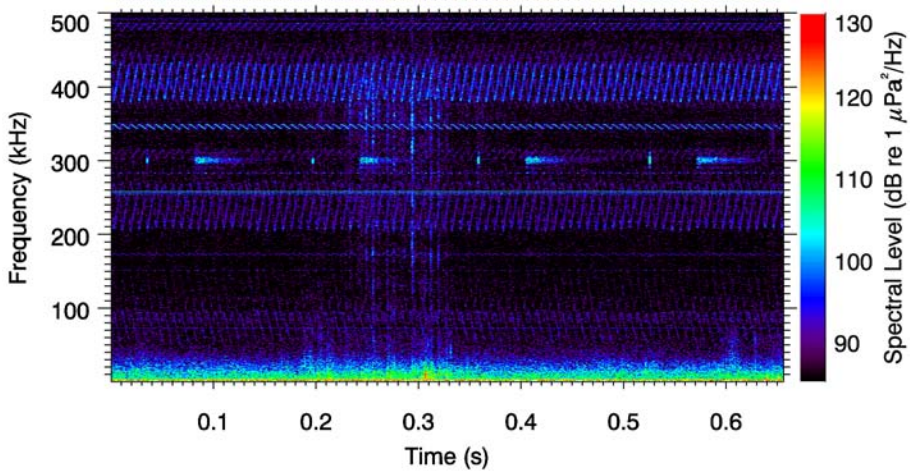


FIGURE 3.46. Spectrogram of four multibeam sonar pulses (Kongsberg EM 3002) measured at 14 m range and 6 m receiver depth. The pulses are centered at 300 kHz and each short (~150 μs) direct-path pulse is followed by a longer (~25 ms) bottom-reflected pulse. The saw-tooth patterns are inducted electromagnetic noise and are not part of the acoustic signal. 4096-pt FFT, 1 MHz sample rate, Hanning window, 512-pt step size.

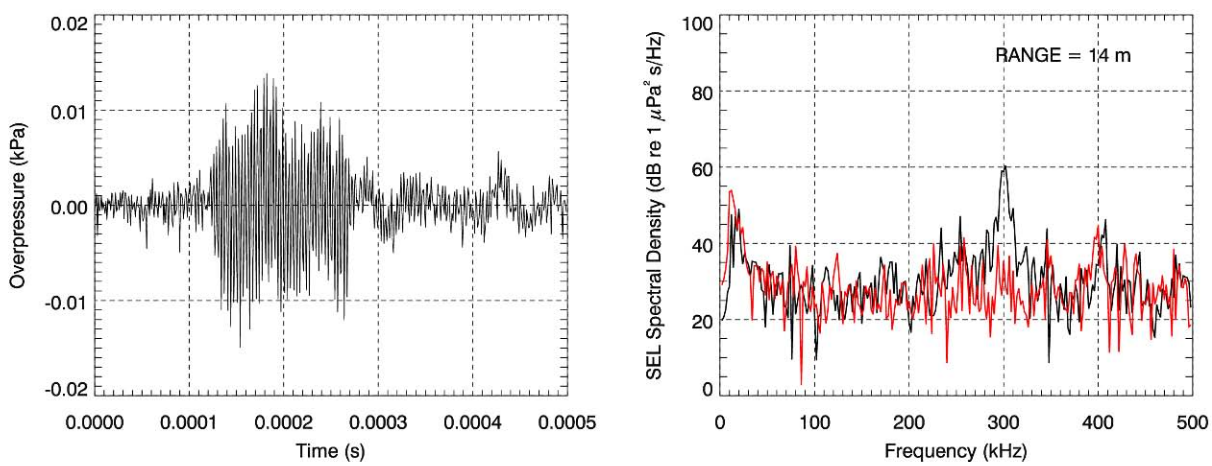


FIGURE 3.47. Multibeam sonar (Kongsberg EM 3002) waveform (left) and SEL spectral density over 0.5 ms (right) of one direct-path pulse at 14 m range and 6 m receiver depth. The corresponding spectral density of background noise from the preceding 0.5 ms window is shown in red. Waveform was high-pass filtered above 10 kHz for display.

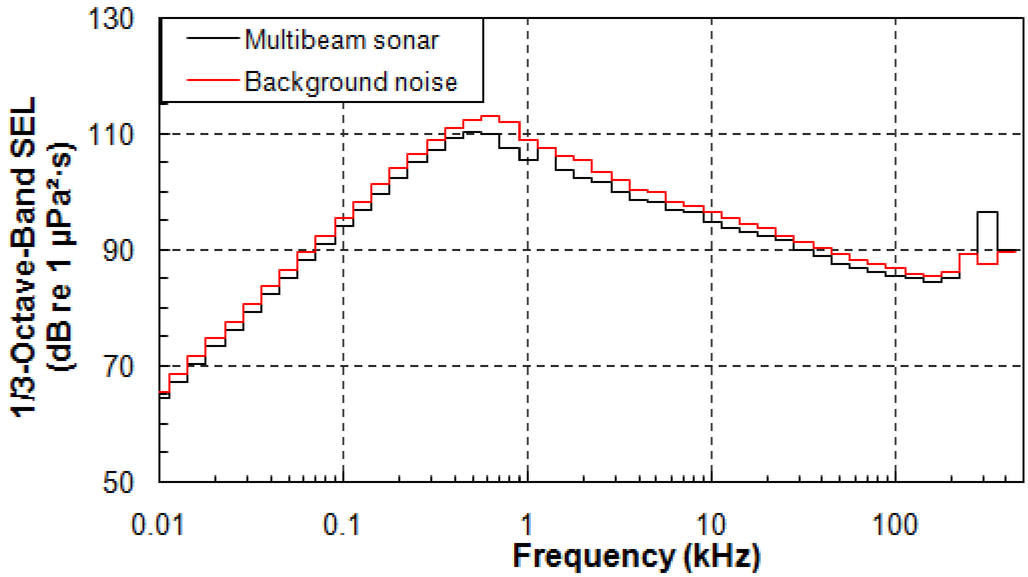


FIGURE 3.48. Multibeam sonar (Kongsberg EM 3002) average 1/3-octave band SEL over 1.5 ms time windows from 10 pulses measured at 14 m range and 6 m receiver depth. The corresponding average band levels of background noise from the preceding 1.5 ms windows are shown in red.

Multibeam Sonar, AUV

The acoustic levels of the AUV multibeam sonar (Kongsberg EM 2000) were measured from the *Ocean Pioneer* during High-Frequency Measurement 2 as the AUV traversed four 1 km long parallel track lines on 7 Sep, with CPAs of 140, 240, 340 and 440 m (AUV SSV Track 4). Sound levels were measured at a hydrophone depth of 2–7 m.

This sonar was also measured at 6–10 m range during High-Frequency Measurement 3, as the AUV was towed behind the *Ocean Pioneer*. The AUV–hydrophone geometry was most stable during the first 2 min of monitoring during the tow measurement, so only data acquired during that time period were analyzed. Sound levels were measured at a hydrophone depth of 1–2 m. It is unknown whether the hydrophone sampled in-beam sound levels during the tow measurement.

To compute absolute received sound levels and source levels, the detected sonar pulses were band-pass filtered from 165 to 210 kHz. Contributions from background noise were computed from the average in-band level of sounds from a 3 ms time window immediately preceding each pulse. Background levels were subtracted from the corresponding pulse levels. The resulting pulse sound levels as a function of range from the monitoring hydrophone are shown in Fig. 3.49. The multibeam sonar is detectable only near the CPA of the track lines, and is not detectable at the 340-m CPA, during which time the background noise rms SPL is 114 dB re 1 µPa in the 165–210 kHz band, nor at the 440-m CPA. The far-field source level terms and distances to sound level thresholds were determined by fitting transmission loss curves to these data, assuming an absorption coefficient of 38.9 dB/km[4] (Table 3.31).

Source levels for the AUV multibeam sonar were estimated also from the average sound levels of the 10 highest rms-amplitude pulses by 20log*R* back-propagation (spherical spreading) and accounting for absorption loss using a coefficient of 38.9 dB/km (Table 3.32). Because the source-receiver range varied

[4] Absorption loss at 200 kHz calculated based on GDEM monthly mean temperature and salinity for Sep at the track line location (Carnes 2009, Teague et al. 1990).

from 6 to 10 m, there is an uncertainty in this measurement which has been quantified by calculating the source level for the minimum and maximum possible ranges. Furthermore, these source levels may not represent in-beam levels since we cannot be sure the hydrophone entered the main beam of the sonar.

A spectrogram of two AUV multibeam pulses is shown in Fig. 3.50 from 10 to 500 kHz. This spectrogram also contains signals from four side-scan sonar pulses and one pulse from the DVL. A multibeam waveform pulse and the corresponding spectral density function are shown in Fig. 3.51. The main frequency lobe is centered at 200 kHz. A weaker frequency lobe centered at 400 kHz is evident, which is perhaps a second vibratory mode of the transducer. There are lower amplitude signals centered at about 300 and 365 kHz. The multibeam pulse rate is approximately 2.8 per second (1 pulse every 0.35 s). The mean 90% rms duration of the 10 highest rms-amplitude pulses is 1 ms.

Un-filtered third-octave band sound levels of the AUV multibeam sonar were calculated as the mean band level over 2 ms time windows of the 10 highest rms-amplitude pulses. These are shown in Fig. 3.52 along with the average band levels of background noise over the 2 ms time windows immediately preceding these pulse windows. The primary and secondary frequency lobes appear in the bands centered at 199.5 and 398.1 kHz, respectively. No frequency components are evident above background levels from the multibeam sonar below the 158.5-kHz band.

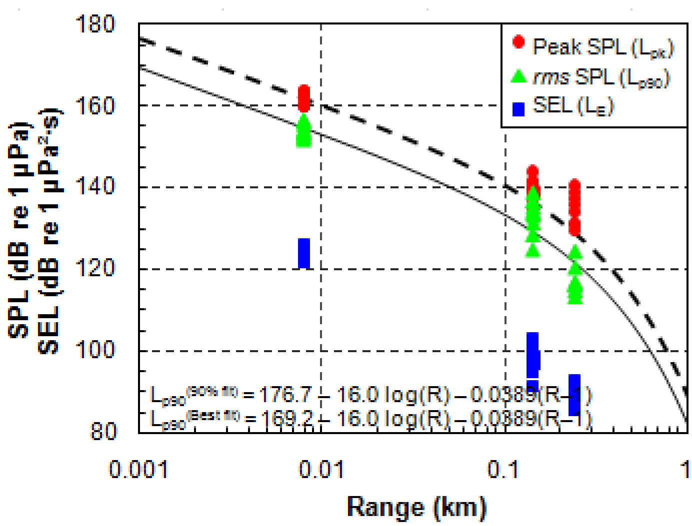


FIGURE 3.49. AUV multibeam sonar (Kongsberg EM 2000) 200-kHz pulse in-beam peak SPL, 90% rms SPL, and SEL versus range, measured at 1–7 m receiver depth. Solid line is best fit of the empirical function to L_{p90} values. Dashed line is the best-fit shifted to exceed 90% of the L_{p90} values (90th percentile fit). Nearest measurements (6–10 m range) may not represent in-beam levels.

TABLE 3.31. AUV multibeam sonar (Kongsberg EM 2000) 200-kHz pulse in-beam source level terms and distances to sound level thresholds (1–7 m receiver depth) from least-squares fit (see Fig. 3.49).

rms SPL threshold (dB re 1 µPa)	Distance (m)	
	Best-fit	90th percentile-fit
190	-	-
180	-	-
170	-	3
160	4	11
150	15	38
140	51	110
130	130	230
120	270	390
SL term (dB re 1 µPa @ 1 m):	169.2	176.7

TABLE 3.32. AUV multibeam sonar (Kongsberg EM 2000) 200-kHz pulse average received sound levels of 10 pulses, measured at 6–10 m range and 1–2 m receiver depth, and source levels derived by 20log*R* back-propagation with 38.9 dB/km absorption loss. May not represent in-beam levels.

	Range (m)	Peak SPL (dB re 1 µPa)	rms SPL (dB re 1 µPa)	SEL (dB re 1 µPa^2·s)
Mean received level	6–10	167.8	162.1	154.2
Lower limit SL	1	183.5	177.9	169.9
Upper limit SL	1	188.1	182.5	174.5

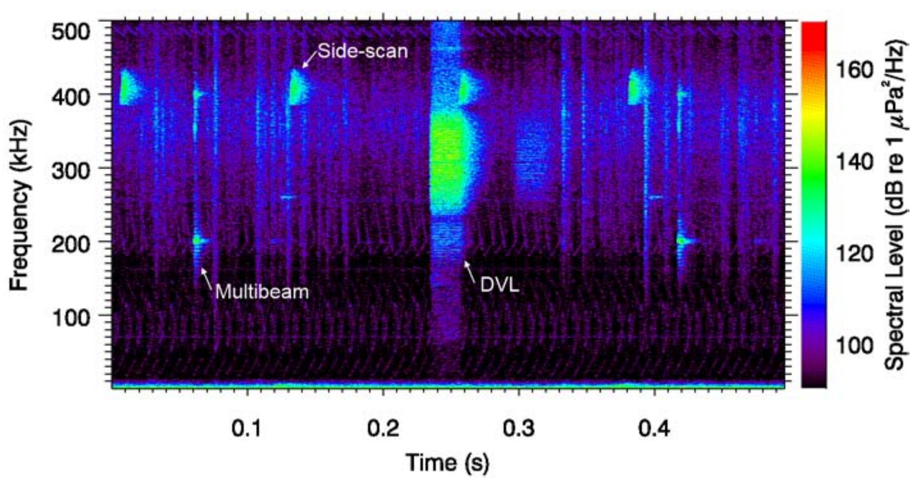


FIGURE 3.50. Spectrogram of two AUV multibeam sonar pulses (Kongsberg EM 2000) measured at 6–10 m range and 1–2 m receiver depth. 4096-pt FFT, 1 MHz sample-rate, Hanning window, 512-pt step size. May not represent in-beam levels.

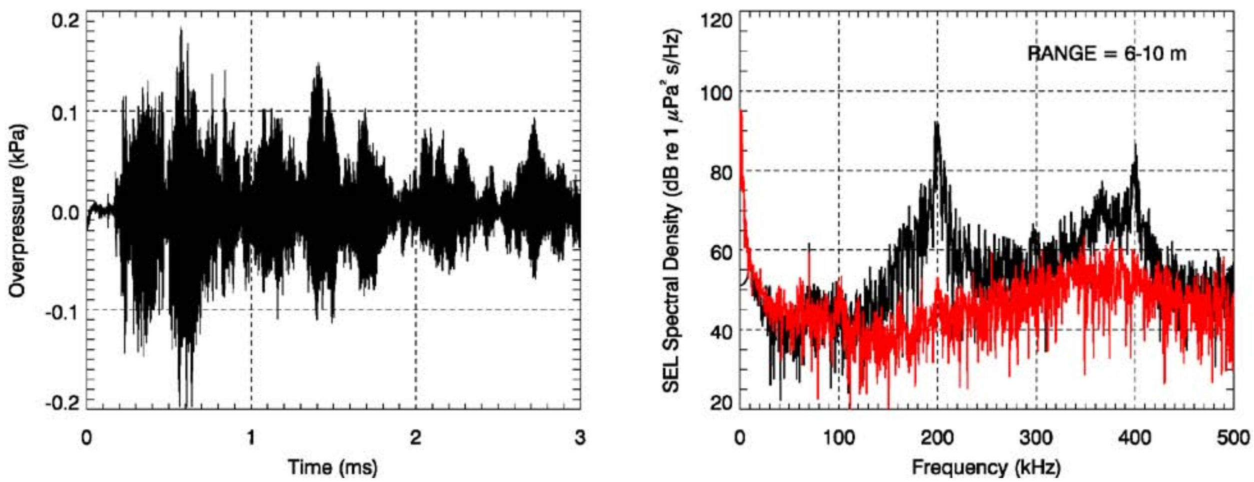


FIGURE 3.51. AUV multibeam sonar (Kongsberg EM 2000) waveform (left) and SEL spectral density over 3 ms time window (right) of one pulse measured at 6–10 m range and 1–2 m receiver depth. The corresponding spectral density of background noise from the preceding 3 ms window is shown in red. Waveform was high-pass filtered above 10 kHz for display. May not represent in-beam levels.

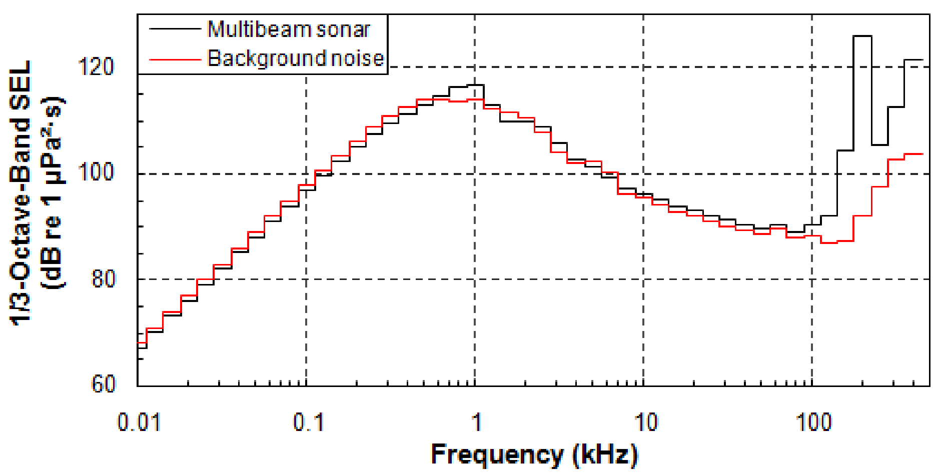


FIGURE 3.52. AUV multibeam sonar (Kongsberg EM 2000) average 1/3-octave band SEL over 2 ms time windows from 10 pulses measured at 6–10 m range and 1–2 m receiver depth. The corresponding average band levels of background noise from the preceding 2 ms windows are shown in red. May not represent in-beam levels.

Side-Scan Sonar, AUV

The AUV side-scan sonar (EdgeTech Dual Frequency) was found to be non-operational during AUV SSV Track 4 (High-Frequency Measurement 2) of 7 Sep, and was consequently measured for 7 min while the AUV was towed behind the *Ocean Pioneer* on 8 Sep, at a source-receiver range of 6–10 m and a hydrophone depth of 1–2 m (High-frequency Measurement 3). The AUV–hydrophone geometry was most stable during the first 2 min of monitoring, so only measurements during this period were analyzed. It is unknown whether the hydrophone sampled in-beam sound levels of the side-scan sonar. The EdgeTech side-scan sonar can produce two pulses simultaneously, but only the 410-kHz pulse was employed and monitored during the program.

The detected sonar pulses were band-pass filtered from 380 to 440 kHz to exclude contributions from background noise for computing absolute received sound levels and source levels. Every fourth side-scan sonar pulse immediately follows a broadband DVL pulse 20 ms in length. These concurrent pulses were omitted by selecting only pulses less than 15 ms long.

Sound levels measured over the first 2 min of monitoring are shown in Fig. 3.53. The source levels of the sonar were estimated from the average sound levels of the 10 highest rms-amplitude pulses by 20log*R* back-propagation (spherical spreading) assuming an absorption coefficient of 100.2 dB/km[5] (Table 3.33). Because the source-receiver range varied from 6 to 10 m and the hydrophone sensitivity varies from -186 dB at 380 kHz to -192 dB at 440 kHz (RESON 2006), the source level (SL) has uncertainty. Consequently the upper and lower limits of the possible SLs were calculated; the lower limit SL assumes 6 m range with -192 dB hydrophone gain, and the upper limit SL assumes 10 m range with -186 dB hydrophone gain. These source levels may not represent in-beam levels, since the hydrophone may not have entered the main beam of the sonar, although we attempted to orient the hydrophone in the beam, and only the 10 highest rms-amplitude pulses were examined.

Sound levels as a function of range were predicted by applying a transmission loss curve to the upper and lower limit source levels given in Table 3.33, based on 20log*R* (spherical) spreading and an absorption coefficient of 100.2 dB/km. These transmission loss curves are plotted in Fig. 3.54 with the 10 highest rms-amplitude pulses measured. Distances to sound level thresholds predicted by these transmission loss curves are given in Table 3.34. Again, these may not represent in-beam sound levels because the hydrophone may not have entered the main beam of the sonar.

A spectrogram from 10 to 500 kHz of five AUV side-scan sonar pulses and two DVL pulses is shown in Fig. 3.55. The pulse repetition rate is 8 per second and the mean 90% rms duration of the 10 highest rms-amplitude pulses is 6.5 ms. The waveform and spectral density of a single pulse are shown in Fig. 3.56. The spectrum of the background noise in the 15 ms window preceding the pulse is also plotted. The pulses have a central frequency at approximately 410 kHz. They are frequency-swept pulses from 385 to 435 kHz, and no frequency components are evident outside the main lobe within the measured frequency range (below 500 kHz).

Third-octave band SELs (un-filtered) were calculated over 15 ms time windows of the 10 highest rms-amplitude pulses. The average band levels are shown in Fig. 3.57 along with the average band levels of background noise over the 15 ms time windows immediately preceding the pulse windows. No frequency components are evident from the side-scan sonar except in the highest 1/3-octave band centered at 398.1 kHz.

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[5] Absorption loss at 410 kHz calculated based on GDEM monthly mean temperature for Sep at the measurement location (1.1°C, Carnes 2009, Teague et al. 1990), averaged over depth, and the mean salinity measured in situ (31.99 ppt, FIGURE 3.20 to FIGURE 3.22).

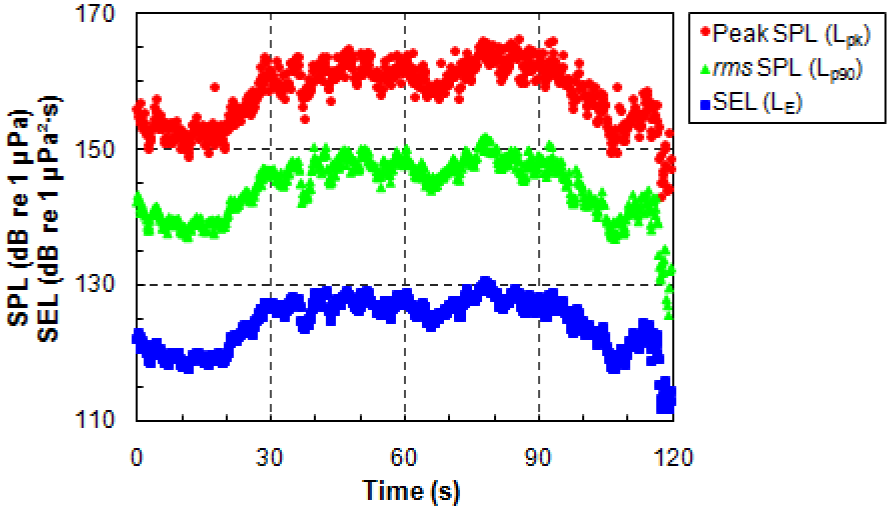

FIGURE 3.53. AUV side-scan sonar (EdgeTech Dual Frequency) 410-kHz pulse peak SPL, 90% rms SPL, and SEL over time measured at 6–10 m range and 1–2 m receiver depth as the AUV was towed behind the *Ocean Pioneer*. May not represent in-beam levels.

TABLE 3.33. AUV side-scan sonar (EdgeTech Dual Frequency) average received sound levels of 10 410-kHz pulses, measured at 6–10 m range and 1–2 m receiver depth, and source levels (SL) derived by 20log*R* back-propagation with an absorption coefficient of 100.2 dB/km. Lower limit SL assumes 6 m range with -192 dB hydrophone gain, and upper limit SL assumes 10 m range with -186 dB hydrophone gain. May not represent in-beam levels.

	Range (m)	Peak SPL (dB re 1 µPa)	rms SPL (dB re 1 µPa)	SEL (dB re 1 µPa^2·s)
Mean received level	6–10	165.0	151.5	130.0
Lower limit SL	1	177.5	164.1	142.6
Upper limit SL	1	188.0	174.5	153.0

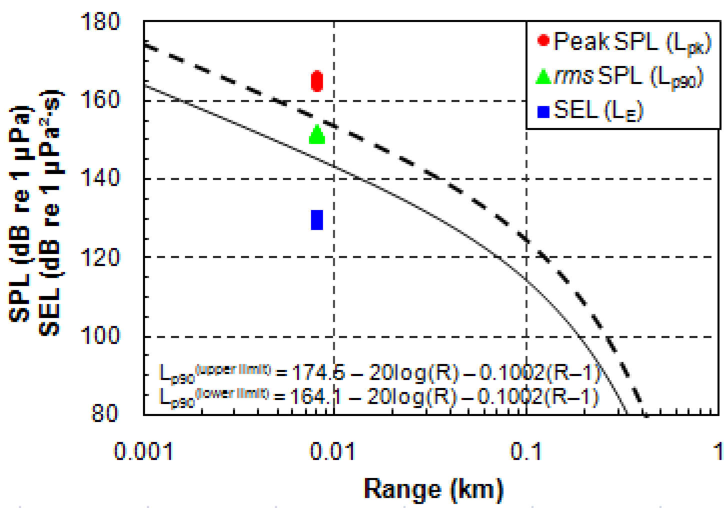

FIGURE 3.54. AUV side-scan sonar (EdgeTech Dual Frequency) 410-kHz pulse peak SPL, 90% rms SPL, and SEL of the 10 highest rms-amplitude pulses, measured at 6–10 m range and 1–2 m receiver depth, and sound levels as a function of range predicted from the upper and lower limit source levels given in Table 3.33 assuming 20log*R* spreading and 100.2 dB/km absorption loss.

TABLE 3.34. AUV side-scan sonar (EdgeTech Dual Frequency) 410-kHz pulse source levels and distances to sound level thresholds (1–2 m receiver depth) predicted from upper and lower limit source levels given in Table 3.33 assuming 20log*R* spreading and abs orption coefficient 100.2 dB/km (see Fig. 3.54). May not represent in-beam levels.

rms SPL threshold (dB re 1 µPa)	Distance (m)
190	-
180	-
170	< 2
160	1–5
150	4–15
140	13–36
130	34–74
120	71–130
SL (dB re 1 µPa @ 1 m):	164.1–174.5

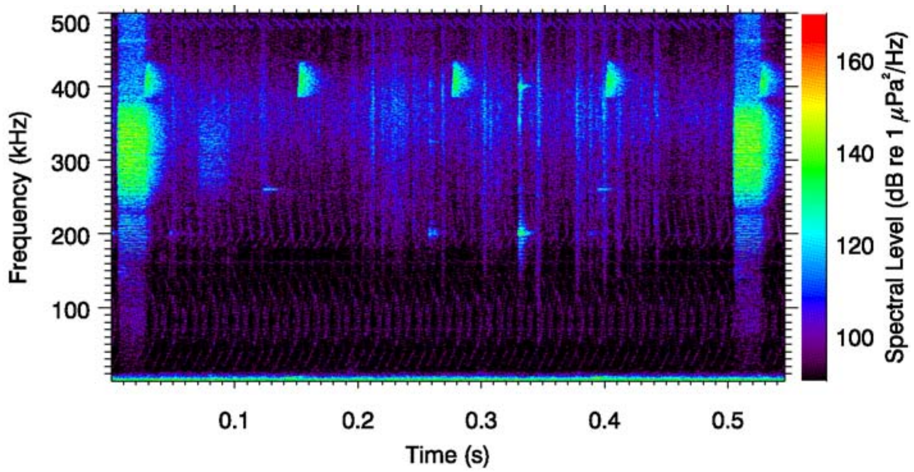

FIGURE 3.55. Spectrogram of five AUV side-scan sonar pulses (EdgeTech Dual Frequency) measured at 6–10 m range and 1–2 m receiver depth. Every fourth side-scan sonar pulse immediately follows a broadband DVL pulse. 4096-pt FFT, 1 MHz sample-rate, Hanning window, 512-pt step size.

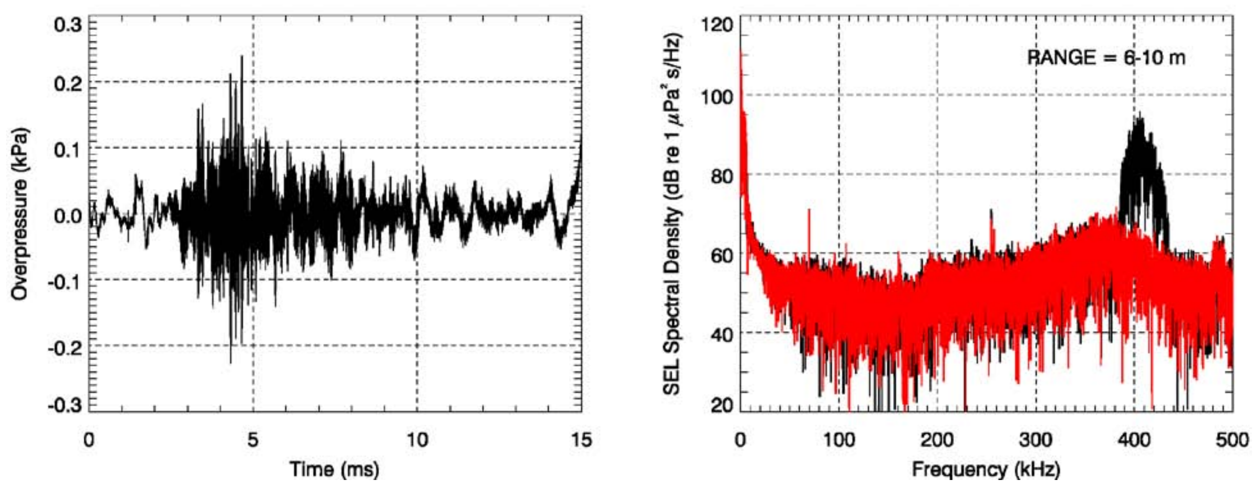

FIGURE 3.56. AUV side-scan sonar (EdgeTech Dual Frequency) waveform (left) and SEL spectral density over 15 ms (right) of one pulse measured at 6–10 m range and 1–2 m receiver depth. The corresponding spectral density of background noise from the preceding 15 ms window is shown in red. Waveform was high-pass filtered above 1 kHz for display.

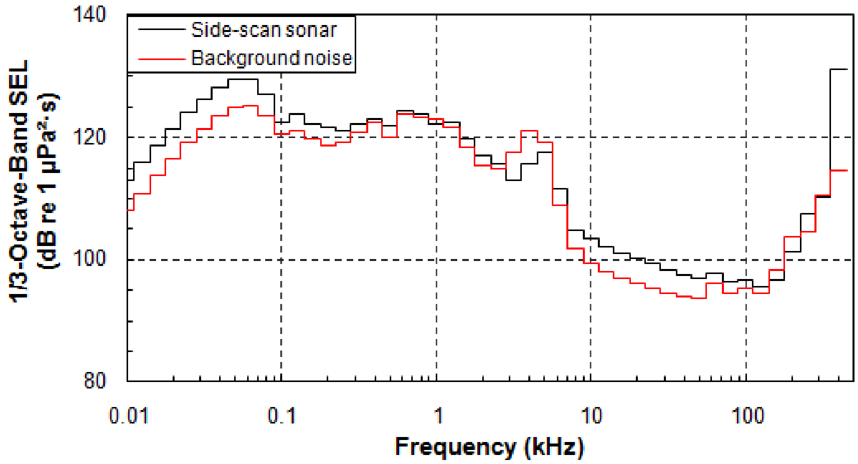

FIGURE 3.57. AUV side-scan sonar (EdgeTech Dual Frequency) average 1/3-octave band SEL over 15 ms time windows from 10 pul ses measured at 6–10 m range and 1–2 m receiver depth. The corresponding average band levels of background noise from the preceding 15 ms windows are shown in red.

Acoustic Communication Signal, AUV

The communications signal from the AUV (Kongsberg HUGIN 1000) was captured by OBH S-03 for 22 min during AUV SSV Track 3 (OBH Deployment 2), at 51 m water depth. The observed pulses are centered at 22 kHz, with peaks at 21.5 and 22.5 kHz that are 30 ms apart.

The detected pulses were isolated with a 20 kHz high-pass filter to remove vessel sounds. The filtered data were analyzed to calculate sound levels as a function of range, shown in Fig. 3.58. Also shown in the plot are least-squares fit functions in the form of Equation 7, which were used to calculate the estimated source level and distances to the sound level thresholds presented in Table 3.35.

A spectrogram of three AUV communication pulses over the full recorded frequency range is presented in Fig. 3.59. The diffuse pulses below 10 kHz were produced by the sub-bottom profiler which was operating concurrently. The unfiltered waveform and spectral density of a single pulse are shown in Fig. 3.60. Peaks at 21.5 and 22.5 kHz are clearly visible, with an overall bandwidth of approximately 7 kHz. Pulses occurred at a rate of about 0.83 Hz (one pulse every 1.2 s), and the mean 90% rms length of the 10 highest rms-amplitude pulses is 217 ms.

Third-octave band levels for AUV communications were calculated from an average of 10 pulses surrounding the 73-m CPA of the AUV in 0.3 s time windows. For comparison, the average band levels of background noise were calculated from 0.3 s windows preceding each pulse window, and both are plotted together in Fig. 3.61. The pulse is evident only in the bands centered at 15.85 and 19.95 kHz.

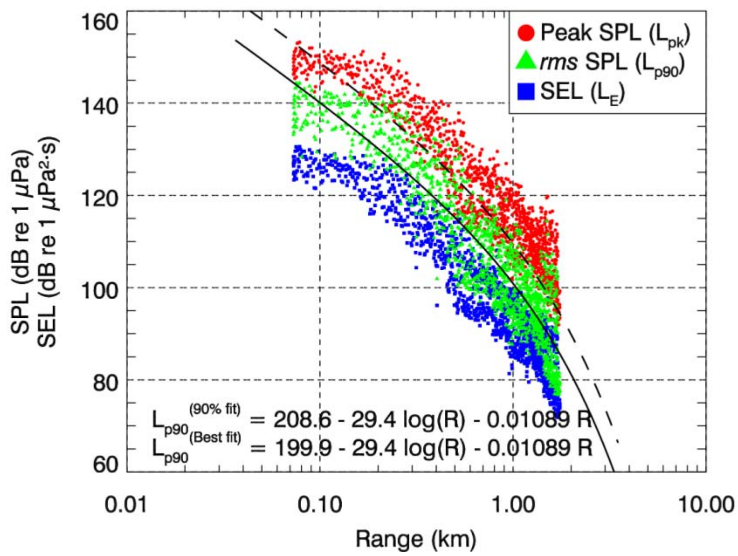

FIGURE 3.58. AUV (Kongsberg HUGIN 1000) communications pulse peak and rms SPL and SEL versus range, measured at 51 m depth. Solid line is best fit of the empirical function to L_{p90} values. Dashed line is the best-fit shifted to exceed 90% of the L_{p90} values (90th percentile fit).

TABLE 3.35. AUV (Kongsberg HUGIN 1000) communications pulse source level terms and distances to sound level thresholds (51 m receiver depth) from least-squares fit (see Fig. 3.58).

rms SPL threshold (dB re 1 μPa)	Distance (m)	
	Best-fit	90th percentile-fit
190	2	4
180	5	9
170	10	20
160	22	43
150	48	91
140	100	190
130	200	350
120	380	610
SL term (dB re 1 μPa @ 1 m):	199.9	208.6

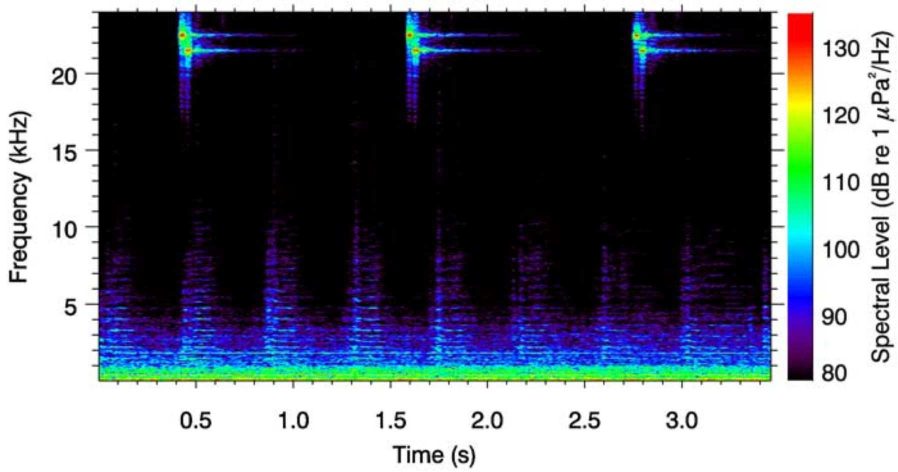

FIGURE 3.59. Spectrogram of three AUV (Kongsberg HUGIN 1000) communication pulses measured at 73 m range and 51 m depth. 2048-pt FFT, 48 kHz sample rate, Hanning window, 256-pt step size.

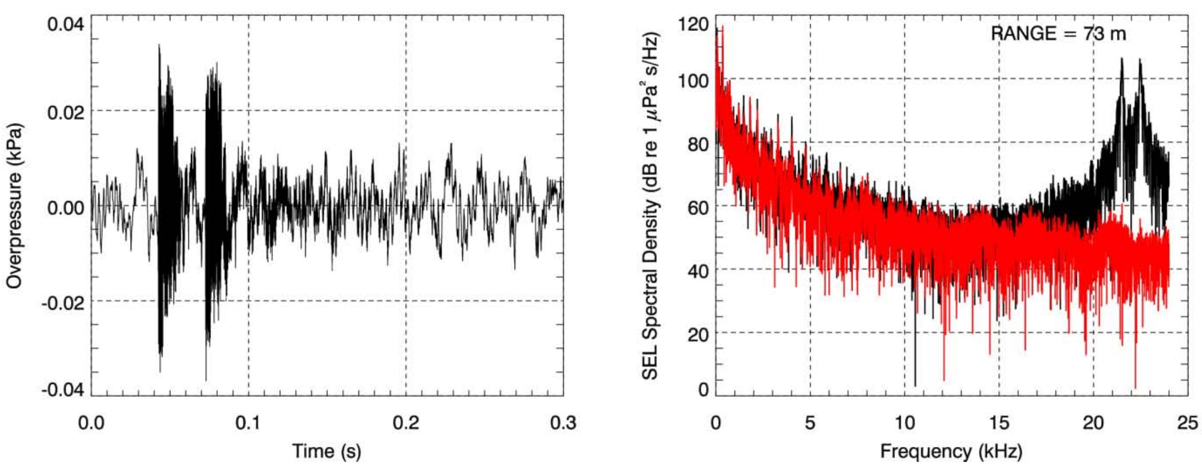

FIGURE 3.60. AUV (Kongsberg HUGIN 1000) communication signal waveform (left) and SEL spectral density over 0.3 s (right) of one pulse measured at 73 m range and 51 m depth. The corresponding spectral density of background noise from the preceding 0.3 s window is shown in red.

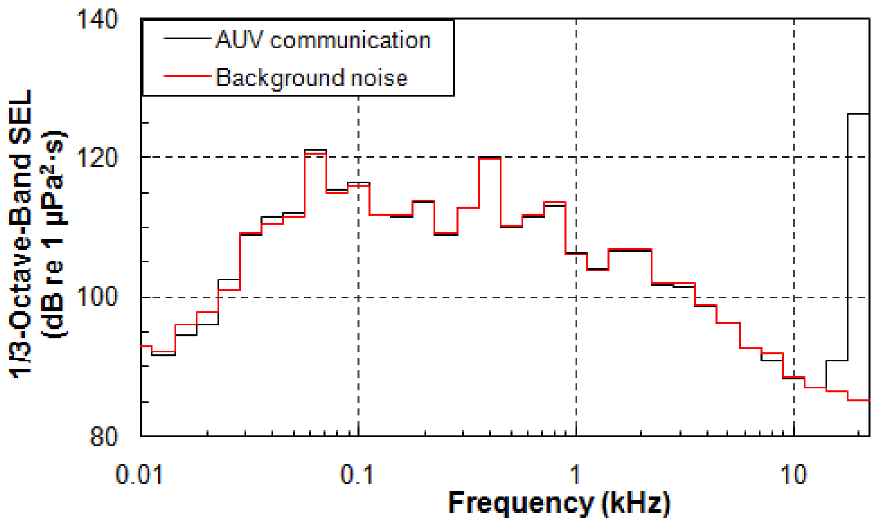

FIGURE 3.61. AUV (Kongsberg HUGIN 1000) communications signal average 1/3-octave band SEL over 0.3-s time windows from 10 pulses measured at 72–74 m range and 51 m depth. The corresponding average band levels of background noise from the preceding 0.3-s windows are shown in red.

Doppler Velocity Log, AUV

Sound pulses from the HUGIN 1000 AUV's Doppler velocity log (DVL) were observed during High-Frequency Measurement 2 of AUV SSV Track 4, at a hydrophone depth of 2–7 m. The AUV traversed four parallel 1-km track lines with CPAs of 140, 240, 340 and 440 m. The DVL was detectable only near the 140 m CPA.

Pulses from the DVL were also present during High-Frequency Measurement 3 from the aft-deck, with the AUV towed behind the *Ocean Pioneer* and a hydrophone depth of 1–2 m. The AUV–hydrophone geometry was most stable during the first 2 min of monitoring, so only measurements during this period were analyzed.

The detected pulses were high-pass filtered at 200 kHz to remove vessel sounds for the SPL calculations. SPL results are presented in Fig. 3.62. To produce sound levels as a function of range in Fig. 3.63, a transmission loss curve was fitted to the 10 highest *rms* SPL pulses from only the 140-m CPA measurement. The equation of the curve is also shown. The estimated source levels and distances to sound level thresholds predicted by this curve are presented in Table 3.36.

Near-field source levels for the DVL were also estimated by back-propagating the average of the 10 highest rms SPL pulses from the aft-deck measurement, assuming 20log*R* (spherical) spreading and an absorption coefficient of 63.3 dB/km[6] (Table 3.37).

A full-frequency spectrogram of three DVL pulses is shown in Fig. 3.64. The un-filtered waveform and spectral density of a single pulse are shown in Fig. 3.65. The pulse spectra are centered at 300 kHz, but are significantly visible above background noise between 100 kHz and the maximum measurement frequency of 500 kHz. Secondary lobes of the main pulse spectrum are visible at 200 and 400 kHz. DVL pulses during the aft-deck measurement were observed at a repetition rate of approximately 2 per second,

[6] Absorption loss at 300 kHz calculated based on GDEM monthly mean temperature for Sep at the measurement location (1.1°C, Carnes 2009, Teague et al. 1990), averaged over depth, and the mean salinity measured in situ (31.99 ppt, FIGURE 3.20 to FIGURE 3.22).

and during the AUV tracks of 7 Sep they occurred at a rate closer to 4 per second. The DVL repetition rate was expected to be depth-dependent.

Third-octave band levels were calculated from an average of 10 near-field pulses, each contained within a 30-ms window (Fig. 3.66). Plotted for comparison are background noise levels from the average of the 30-ms windows immediately preceding the pulse windows. Frequency components from the DVL are visible in all bands above 90 kHz.

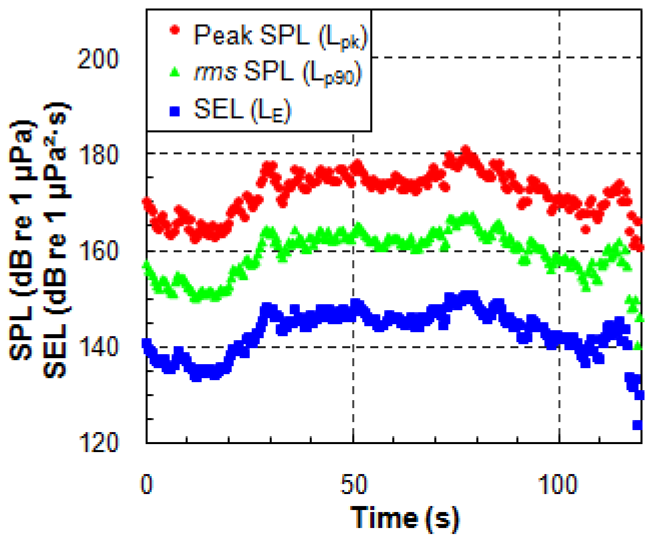

FIGURE 3.62. AUV (Kongsberg HUGIN 1000) Doppler velocity log, 300-kHz pulse, peak SPL, 90% rms SPL, and SEL over time measured at 6–10 m range and 1–2 m receiver depth.

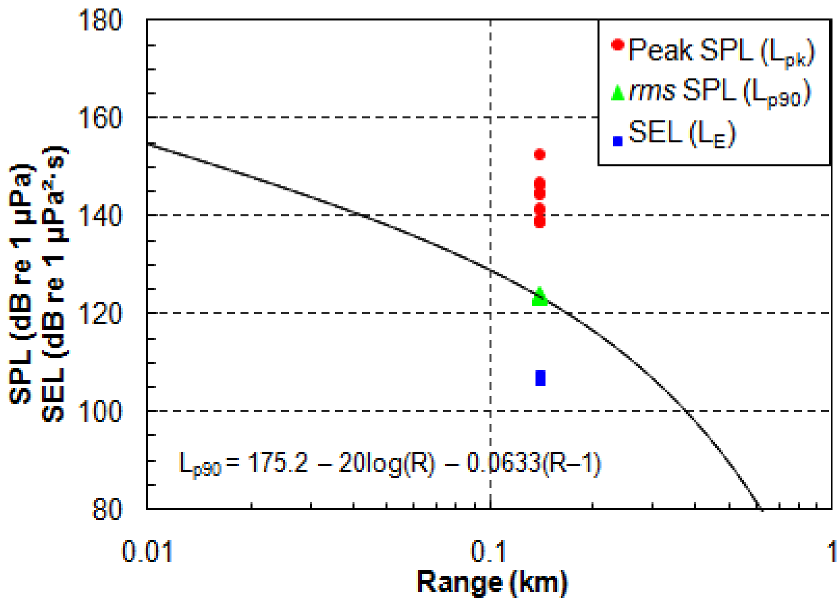

FIGURE 3.63. AUV (Kongsberg HUGIN 1000) Doppler velocity log 300-kHz pulse peak SPL, 90% rms SPL, and SEL versus range, measured at 2–7 m receiver depth. Solid line is based on back-propagated SL from 140-m CPA measurement, assuming 20log*R* spreading and 63.3 dB/km absorption loss.

TABLE 3.36. AUV (Kongsberg HUGIN 1000) Doppler velocity log 300-kHz pulse source level term and distances to sound level thresholds (2–7 m receiver depth) from back-propagated SL assuming 20log*R* spreading and 63.3 dB/km absorption loss (see Fig. 3.63).

rms SPL threshold (dB re 1 µPa)	Distance (m)
190	-
180	-
170	2
160	6
150	16
140	42
130	93
120	170
SL (dB re 1 µPa @ 1 m):	175.2

TABLE 3.37. AUV (Kongsberg HUGIN 1000) Doppler velocity log average received sound levels of 10 300-kHz pulses, measured at 6–10 m range and 1–2 m receiver depth, and source levels (SL) derived by 20log*R* back-propagation with 63.3 dB/km absorption loss.

	Range (m)	Peak SPL (dB re 1 µPa)	rms SPL (dB re 1 µPa)	SEL (dB re 1 µPa^2·s)
Mean received level	6-10	179.2	166.8	150.1
Lower Limit SL	1	195.1	182.6	165.9
Upper Limit SL	1	199.8	187.3	170.6

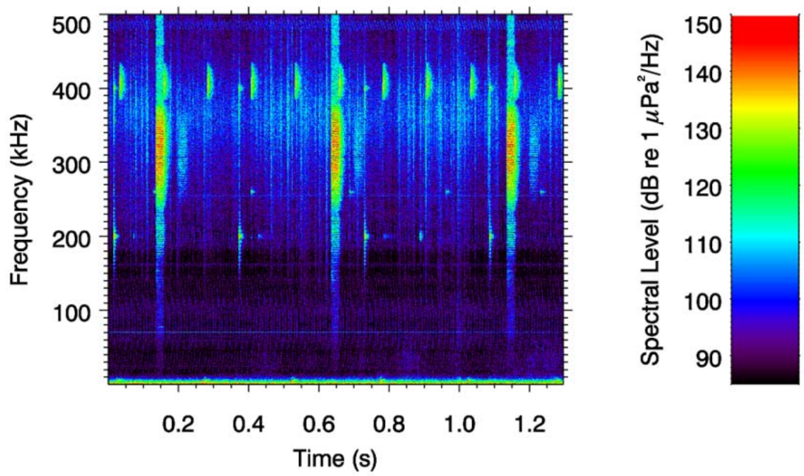

FIGURE 3.64. Spectrogram of three AUV (Kongsberg HUGIN 1000) Doppler velocity log pulses measured at 6–10 m range and 1–2 m receiver depth. 4096-pt FFT, 1 MHz sample rate, Hanning window, 512-pt step size.

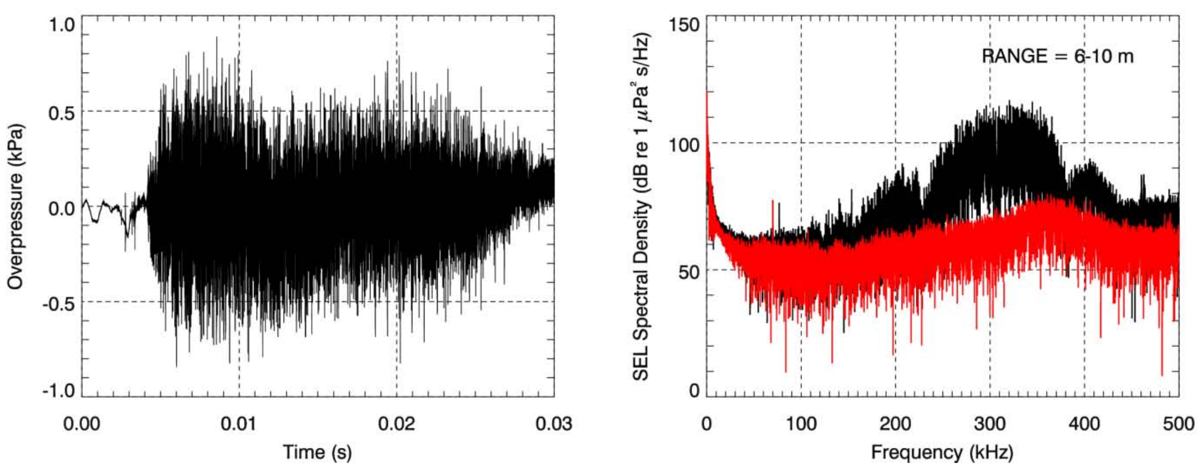

FIGURE 3.65. AUV (Kongsberg HUGIN 1000) Doppler velocity log waveform (left) and SEL spectral density (right) over 30 ms of one pu lse at 6–10 m range and 1–2 m receiver depth. The corresponding spectral density of background noise from the preceding 30 ms window is shown in red.

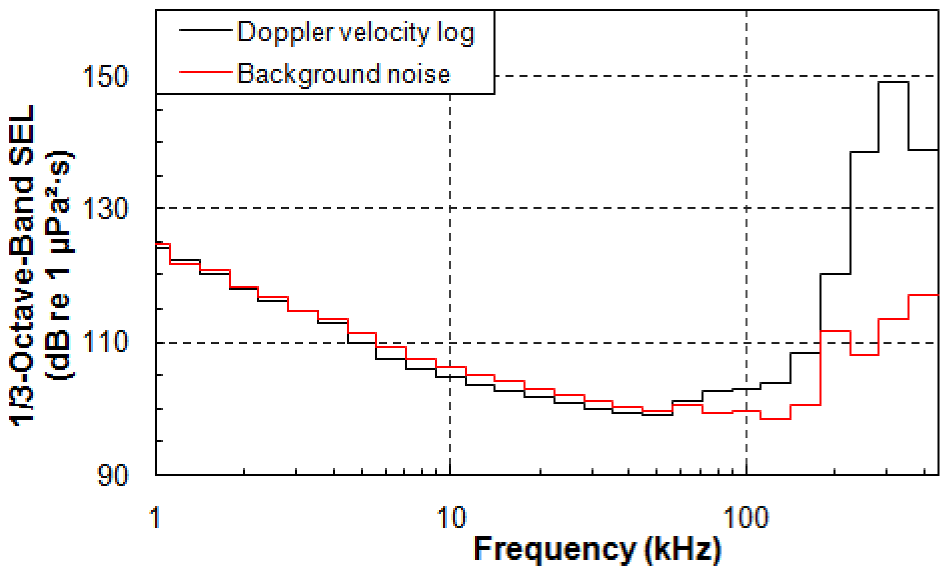

FIGURE 3.66. AUV (Kongsberg HUGIN 1000) Doppler velocity log average 1/3-octave band SEL over 30 ms time windows from 10 pulses measured at 6–10 m range and 1–2 m receiver depth. The corresponding average band levels of background noise from the preceding 30 ms windows are shown in red.

<u>*Camden Bay, Beaufort Sea*</u>

R/V Ocean Pioneer Self-Noise, Transiting

Vessel noise produced by the *R/V Ocean Pioneer* transiting at 3.2 kts was measured during OBH Deployment 3 on 19 Aug during SSV Track 5. At the closest points of approach, the *Ocean Pioneer* was 23 m and 212 m away from OBHs S-02 and S-03, respectively, in 37–38 m water depth.

Continuous sound levels were analyzed in 1-s time windows over the SSV Track. Fig. 3.67 shows rms SPL versus time from each OBH. The peak in each plot indicates the time of CPA relative to the SSV Track start time. Fig. 3.68 shows rms SPL versus range from both OBHs in the forward and aft directions. Distances to sound level thresholds (Table 3.38) were determined from transmission loss curve fits to these data. Spectrograms of 6 min surrounding each CPA are shown in Fig. 3.69. Mean power spectral density (PSD) was calculated from 10 s centered on each CPA and is shown in Fig. 3.70.

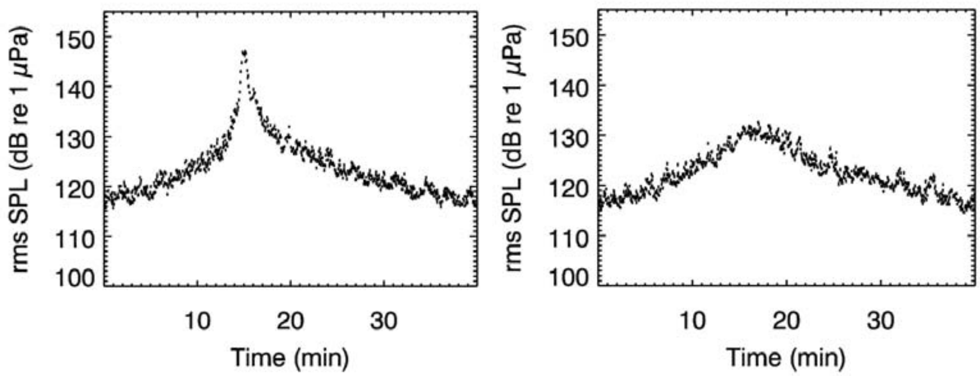

FIGURE 3.67. *Ocean Pioneer* rms SPL versus time, in 1-s intervals while transiting at 3.2 kts measured at OBH S-02 with a 23 m CPA (left) and S-03 with a 212 m CPA (right).

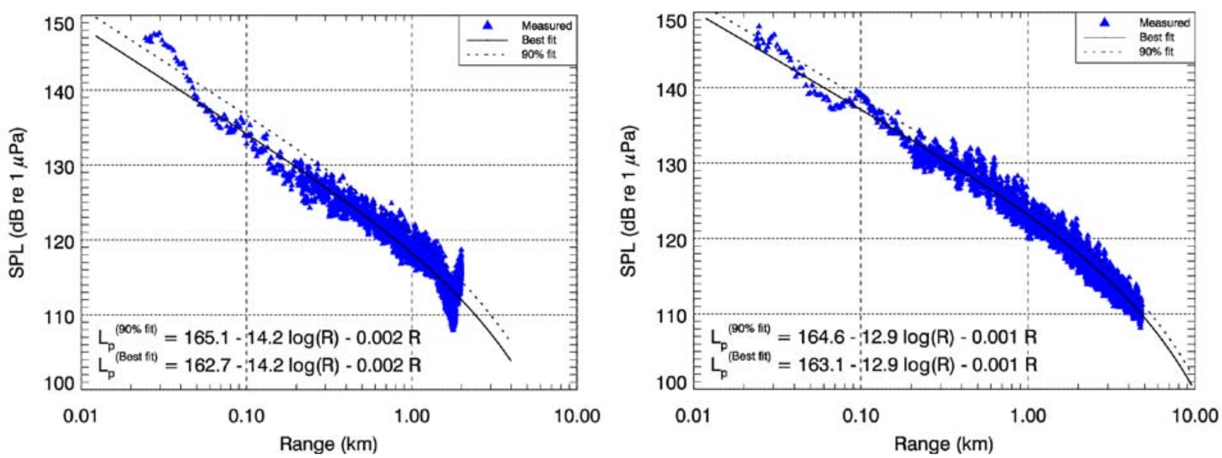

FIGURE 3.68. *Ocean Pioneer* rms SPL versus range while transiting at 3.2 kts in the fore (left) and aft (right) directions, including data from both OBHs. Solid line is best fit of the empirical function to L_{p90} values. Dashed line is the best-fit shifted to exceed 90% of the L_{p90} values (90th percentile fit).

TABLE 3.38. Distance to rms SPL thresholds for the *Ocean Pioneer* transiting at 3.2 kts in the forward and aft directions.

rms SPL threshold (dB re 1 μPa)	Forward of *Ocean Pioneer*		Aft of *Ocean Pioneer*	
	Best-fit	90th percentile-fit	Best-fit	90th percentile-fit
160	2	2	2	2
150	8	12	10	13
140	39	59	60	79
130	190	270	340	430
120	800	1100	1600	1900
SL term (dB re 1 μPa @ 1 m)	162.7	165.1	163.1	164.6

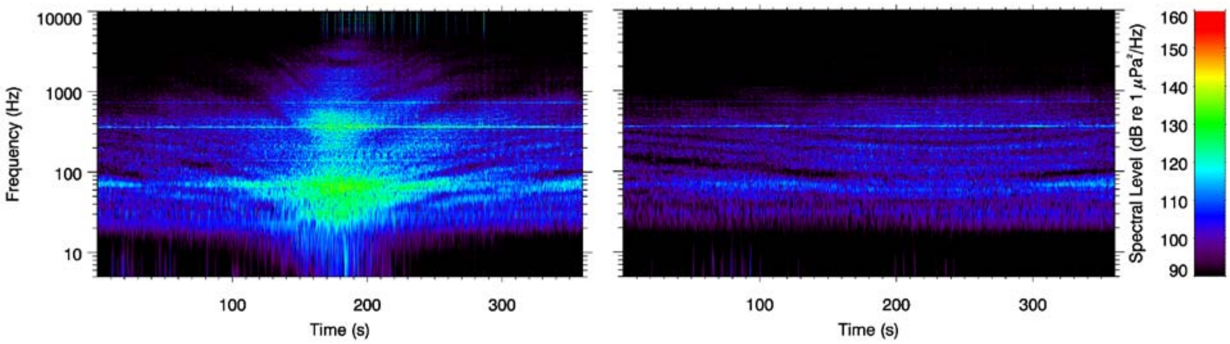

FIGURE 3.69. Spectrograms of the *Ocean Pioneer* transiting at 3.2 kts at 23 m (left) and 212 m (right) range. 8192-pt FFT, 32 kHz sample rate, Hanning window, 1024-pt step size.

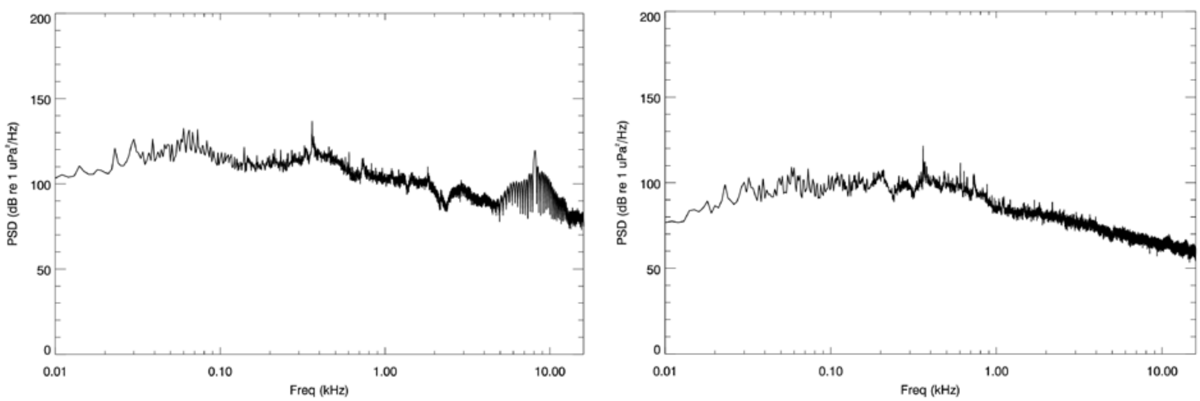

FIGURE 3.70. Average power spectral density (PSD) of the *Ocean Pioneer* transiting at 3.2 kts over a 10-s window at the 23-m (left) and 212-m (right) CPAs.

Sub-Bottom Profiler, Towfish

Underwater sound from the sub-bottom profiler towfish (EdgeTech 3100 SB-216S) was measured using an OBH as the profiler was towed by the *Ocean Pioneer* along SSV track 6. The measurement was done on 20 Aug as the profiler approached and departed the OBH. The OBH was deployed at the Camden Bay location in 36.9 m water depth, with the hydrophone approximately 3 m above the seafloor. The profiler was towed at a nominal depth of 5 m and the CPA was 192 m slant range.

Fig. 3.71 shows sound levels versus slant range for the sub-bottom profiler pulses. The pulses were high-pass filtered to 1 kHz to omit contributions from other noise sources. A curve of the form Equation 7 was fit to the data and the resulting distances to threshold levels are listed in Table 3.39.

A spectrogram of three sub-bottom profiler pulses measured at the CPA of 192 m slant range is shown in Fig. 3.72. The pulse firing rate was approximately 300 ms with nominal pulse duration of 50 ms. The spectrogram shows an up-sweep frequency pattern from 3 to 11 kHz.

Fig. 3.73 shows a sub-bottom profiler pulse waveform, spectrum, and background spectrum measured at the CPA of 192 m slant range. The waveform has been hi-pass filtered at 1 kHz and the spectra are shown at frequencies above 1 kHz. The pulse spectrum exceeds background levels at frequencies between 3.5 and 11.5 kHz, agreeing with the 3–12 kHz profiler setting used during the measurement.

Fig. 3.74 shows third-octave band levels of an average of the spectra of the 10 highest rms-amplitude pulses near CPA and of the background noise from a 50 ms window preceding the pulses. The band levels are highest in the 6.2 kHz frequency band and exceed background levels in frequency bands centered between 4 and 11 kHz.

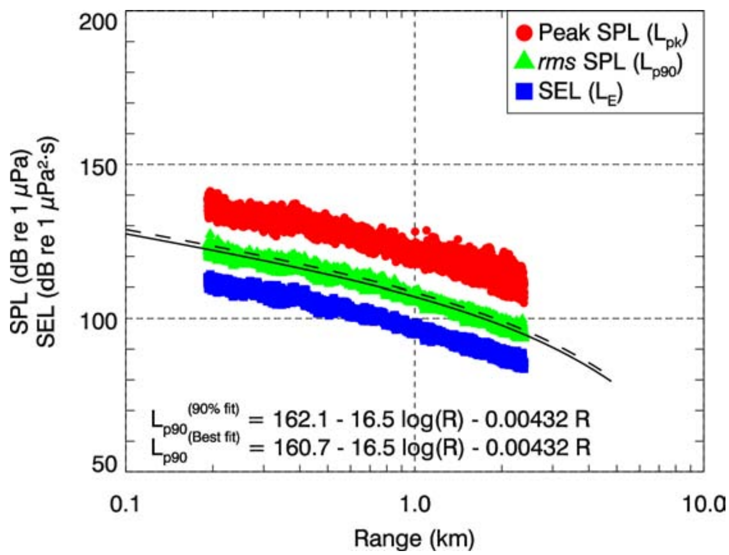

FIGURE 3.71. Sub-bottom profiler (EdgeTech 3100 SB-216S) peak SPL, 90% rms SPL, and SEL versus range (34 m receiver depth). Solid line is best fit of the empirical function to L_{p90} values. Dashed line is the best-fit shifted to exceed 90% of the L_{p90} values (90th percentile fit). Pulses beyond 5.5 km range were indistinguishable from background noise.

TABLE 3.39. Sub-bottom profiler towfish (EdgeTech 3100 SB-216S) source level terms and di stances to sound level thresholds (34 m receiver depth) from least-squares fit (see Fig. 3.71).

rms SPL threshold (dB re 1 μPa)	Slant Range (m)	
	Best-fit	90^{th} percentile-fit
160	1*	1*
150	4*	5*
140	18*	22*
130	70*	85*
120	260	300
110	760	870
100	1700	1900
SL term (dB re 1 μPa @ 1 m):	160.7	162.1

*Extrapolated values, less than minimum measurement slant range of 192 m.

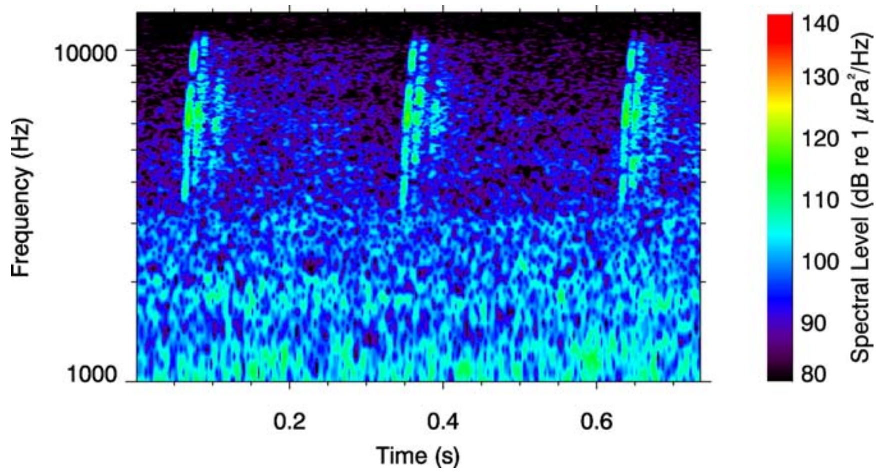

FIGURE 3.72. Spectrogram of three sub-bottom profiler (EdgeTech 3100 SB-216S) pulses at the CPA of 192 m slant range. 512-pt FFT, 32 kHz sample-rate, Hanning window, 64-pt step size.

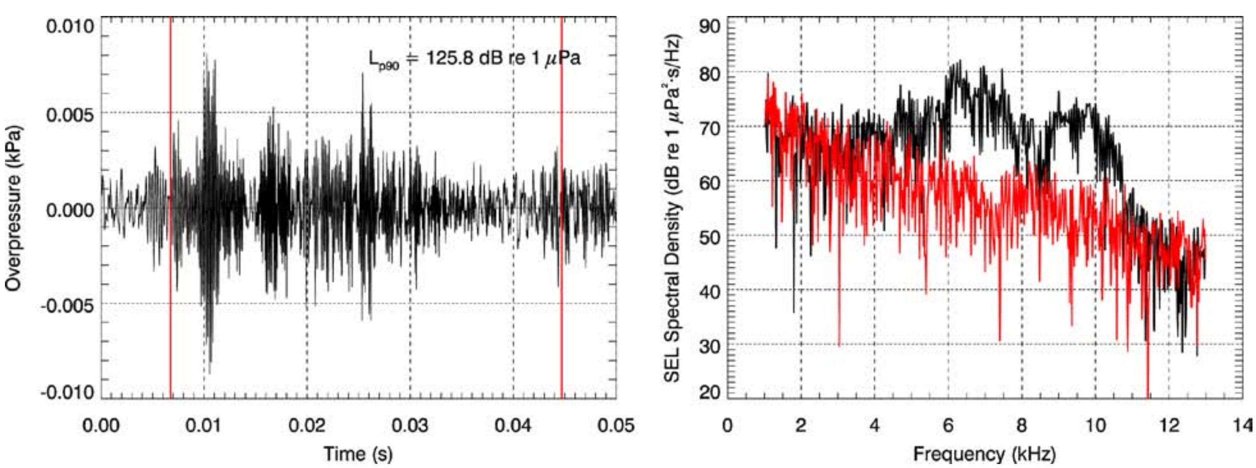

FIGURE 3.73. Sub-bottom profiler waveform (left) and SEL spectral density over 50 ms (right) of one pulse measured at the CPA of 192 m slant range and 34 m receiver depth. Waveform was 1 kHz high-pass filtered. The corresponding spectral density of background noise from the preceding 50-ms window is shown in red.

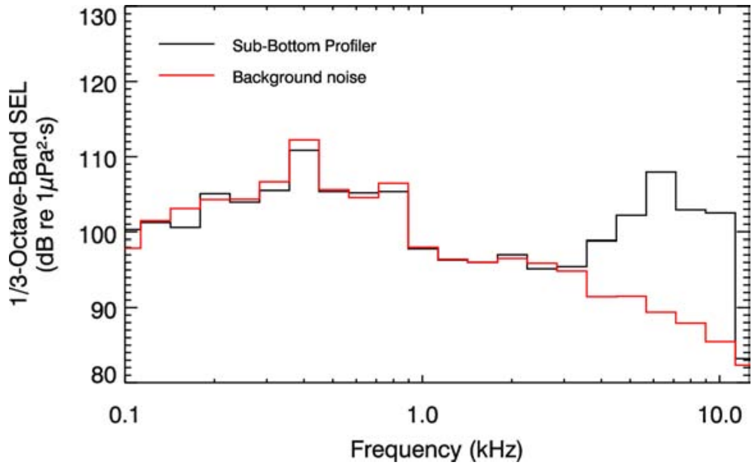

FIGURE 3.74. Sub-bottom profiler (EdgeTech 3100 SB-216S) 1/3-octave band SEL over a 50 ms time window averaged over the 10 highest rms-amplitude pulses measured at the CPA of 192 m slant range and 34 m receiver depth. The corresponding average band levels of background noise from the 10 preceding 50-ms windows are shown in red.

Mini-Cone Penetrometer

Sound levels of the mini-cone penetrometer, operated by Gregg Drilling, were measured during OBH Deployment 3 on 19 Aug at 40 m source-receiver range to the nearest OBH and 38 m water depth. The *Ocean Pioneer*, operating in DP mode, was located at 55 m slant range to the nearest OBH. To compare mini-CPT sound levels to background noise and the *Ocean Pioneer*, two 9-min time windows were analyzed: one while the *Ocean Pioneer* was operating in DP mode with the mini-CPT aboard, and one during mini-CPT operations on the seabed.

Third-octave band sound levels averaged over the mini-CPT operation window are shown in Fig. 3.75. Shown in the same plot are average band levels of the *Ocean Pioneer* operating in DP mode, which were calculated from a 9-min window while the mini-CPT was still aboard. The mini-CPT is not significantly evident over the vessel thrusters in any band.

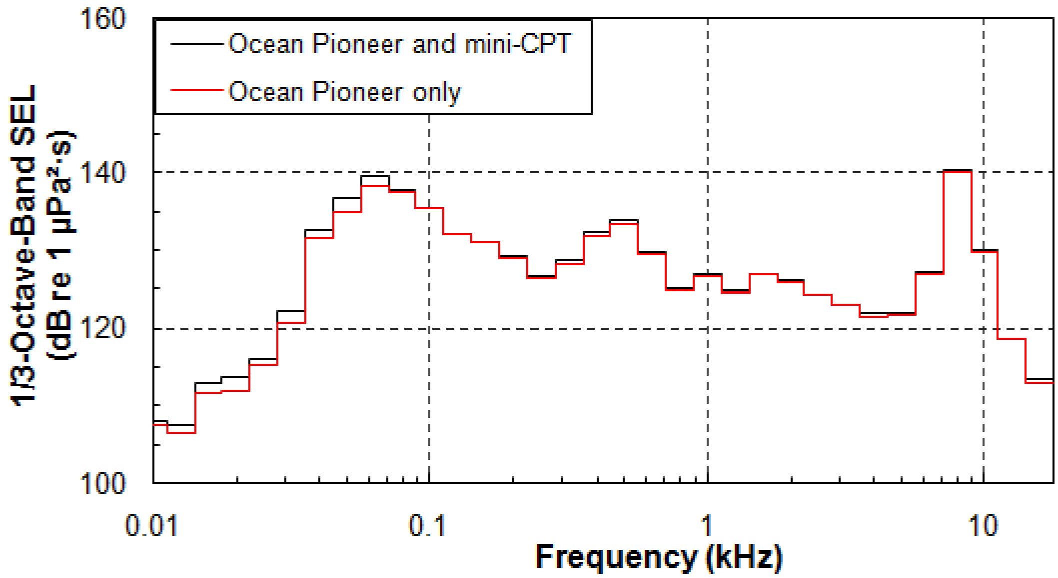

FIGURE 3.75. Mini-cone penetrometer average 1/3-octave band SEL over 1 s time windows from 9 min of operation measured at 40 m range and 38 m receiver depth. These levels are representative of thruster levels only since the mini-CPT sounds were too low to be resolved during this measurement. The corresponding average band levels of background noise from 9 min of the *Ocean Pioneer* operating in DP mode are shown in red.

<u>*Harrison Bay, Beaufort Sea*</u>

R/V Ocean Pioneer Self-Noise, Transiting

Vessel noise produced by the *R/V Ocean Pioneer* transiting at 3.4 kts was measured during OBH Deployment 4 on 27 Aug during SSV Track 7. At the closest point of approach, the *Ocean Pioneer* was 22 m away from OBH S-03, in 19.5 m water depth.

Continuous sound levels were analyzed in 1 s time windows over the SSV Track (Fig. 3.76). The sharp peak in the plot indicates the time of CPA relative to the SSV Track start time. Fig. 3.77 shows rms SPL versus range in the forward and aft directions. Distances to sound level thresholds (Table 3.40) were determined from transmission loss curve fits to these data. A spectrogram of 6 min surrounding the CPA is shown in Fig. 3.78. Mean power spectral density (PSD) was calculated from 10 s centered on the CPA and is shown in Fig. 3.79.

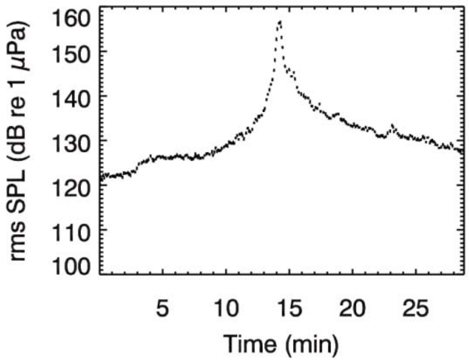

FIGURE 3.76. *Ocean Pioneer* rms SPL in 1-s intervals while transiting at 3.4 kts measured at the 22 m CPA.

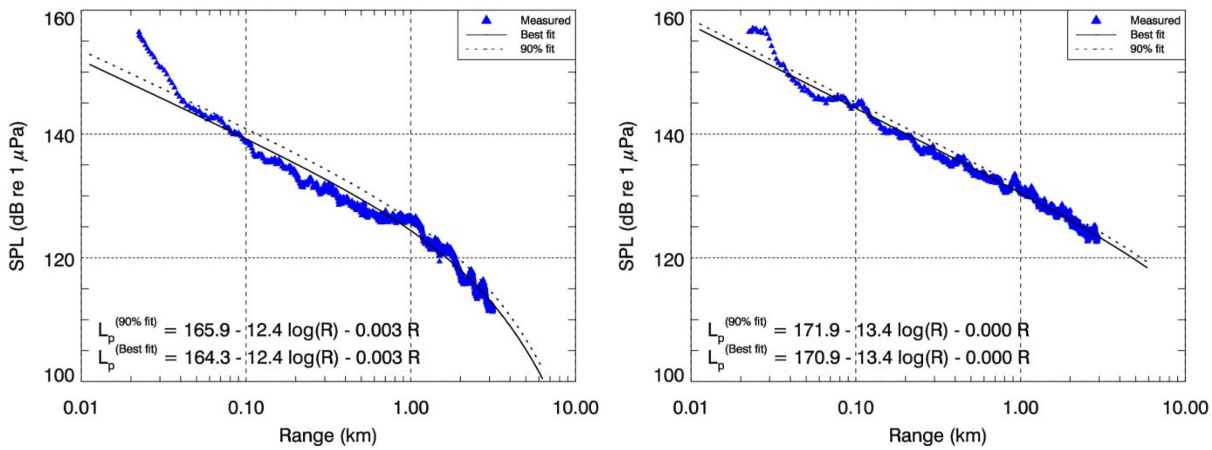

FIGURE 3.77. Sound pressure level (rms) versus range from the *R/V Ocean Pioneer* transiting at 3.4 kts, in fore (left) and aft (right) directions. Solid line is best fit of the empirical function to L_{p90} values. Dashed line is the best-fit shifted to exceed 90% of the L_{p90} values (90th percentile fit).

TABLE 3.40. Sound level threshold radii for the *R/V Ocean Pioneer* transiting at 3.4 kts, in the forward and aft directions.

rms SPL threshold (dB re 1 μPa)	Radius forward of *Ocean Pioneer*		Radius aft of *Ocean Pioneer*	
	Best-fit (m)	90th percentile-fit (m)	Best-fit (m)	90th percentile-fit (m)
160	2	3	7	8
150	14	19	37	43
140	87	120	200	240
130	460	590	1100	1200
120	1600	1900	4800	5400
SL term (dB re 1 μPa @ 1 m):	164.3	165.9	170.9	171.9

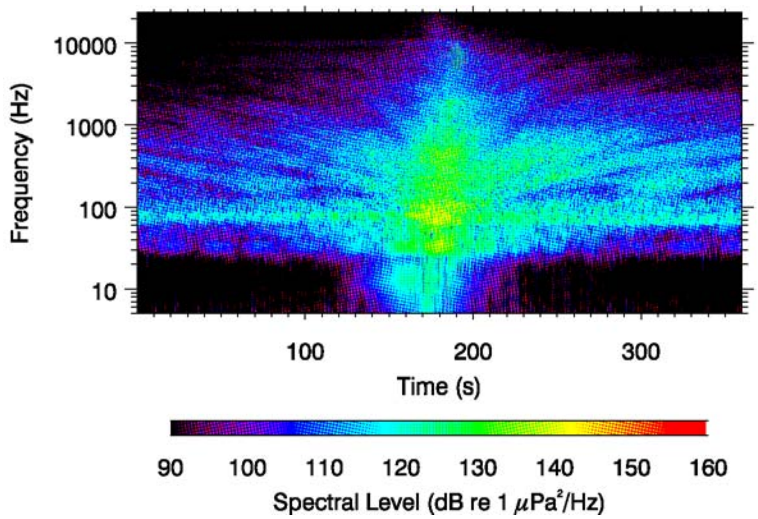

FIGURE 3.78. Spectrogram of *R/V Ocean Pioneer* transiting at 3.4 kts, with a CPA of 22 m. 8192-pt FFT, 48 kHz sample rate, Hanning window, 1024-pt step size.

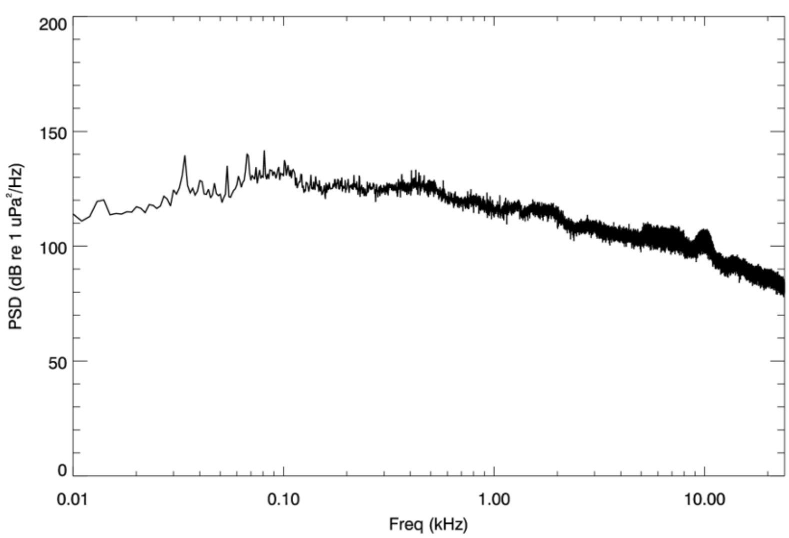

FIGURE 3.79. Average power spectral density (PSD) of the *Ocean Pioneer* transiting at 3.4 kts over a 10-s window centered at the 22-m CPA.

Sub-Bottom Profiler, Towfish

Underwater sound from the sub-bottom profiler towfish (EdgeTech 3100 SB-216S) was measured using an OBH as the profiler was towed by the *Ocean Pioneer* along SSV Track 7. The measurement was done on 27 Aug 2010 as the profiler approached and departed the OBH. The OBH was deployed at the Harrison Bay location in 19.5 m water depth, with the hydrophone approximately 3 m above the seafloor. The profiler was towed at a nominal depth of 5 m and the CPA was 20 m slant range.

Fig. 3.80 shows sound levels versus slant range for the sub-bottom profiler pulses. The pulses were high-pass filtered to 1 kHz to omit contributions from other noise sources. A curve of the form Equation 8 was fit to the data and the resulting distances to threshold levels are listed in Table 3.41. Sound levels at slant ranges less than 30 m are higher than the curve fits because the OBH was in the main beam of the sub-bottom profiler. Pulses beyond 5.5 km range were indistinguishable from background noise.

A spectrogram of three sub-bottom profiler pulses measured at the CPA of 20 m slant range is shown in Fig. 3.81. The pulse firing rate was approximately 300 ms with nominal pulse duration of 20 ms. The spectrogram shows an up-sweep frequency pattern from 3 to 11 kHz.

Fig 3.82 shows a sub-bottom profiler pulse waveform, spectrum, and background spectrum measured at the CPA of 20 m slant range. The waveform has been high-pass filtered at 120 Hz and the spectra are shown at frequencies above 1 kHz. The pulse spectrum exceeds background levels at frequencies between 3.5 and 11.5 kHz, agreeing with the 3–12 kHz profiler setting used during the measurement.

Fig. 3.83 shows third-octave band levels of an average of the spectra of the 10 highest rms-amplitude pulses near CPA and of the background noise from a 25 ms window preceding the pulses. The band levels are highest in the 6.2 kHz frequency band and exceed background levels in frequency bands centered between 3.2 and 11 kHz.

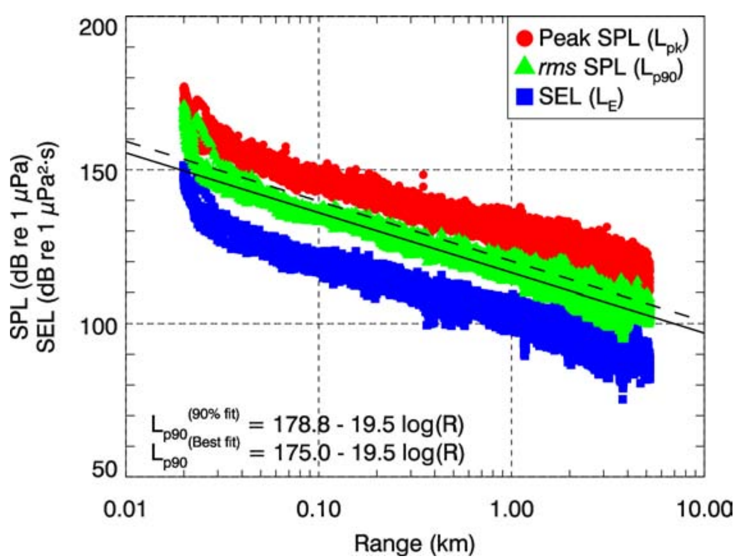

FIGURE 3.80. Sub-bottom profiler (EdgeTech 3100 SB-216S) peak SPL, 90% rms SPL, and SEL versus range, 17 m receiver depth. Solid line is best fit of the empirical function to L_{p90} values. Dashed line is the best-fit shifted to exceed 90% of the L_{p90} values (90th percentile fit).

TABLE 3.41. Sub-bottom profiler (EdgeTech 3100 SB-216S) source level terms and distances to sound level thresholds (17 m receiver depth) from least-squares fit (see Fig. 3.80).

rms SPL threshold (dB re 1 μPa)	Slant Range (m)	
	Best-fit	90th percentile-fit
190	[16]	[16]
180	[17]	[18]
170	[19]	[20]
160	6*, [21]	9*, [22]
150	19*, [24]	30, [24]
140	62	97
130	200	310
120	660	1000
110	2100	3300
100	6900	11,000
SL term (dB re 1 μPa @ 1 m):	175.0	178.8

*Less than minimum measurement slant range of 20 m.
[n] Based on a separate near-CPA analysis where the OBH is partly insonified by the main lobe of the projector, extrapolated if less than minimum measurement slant range of 20 m.

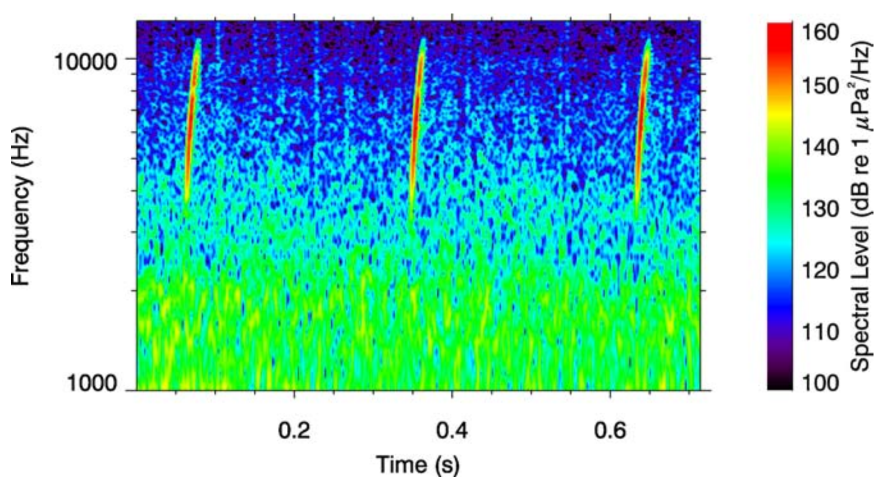

FIGURE 3.81: Spectrogram of three sub-bottom profiler (EdgeTech 3100 SB-216S) pulses at the CPA of 20 m slant range, 512-pt FFT, 48 k Hz sample-rate, Hanning window, 64-pt step size.

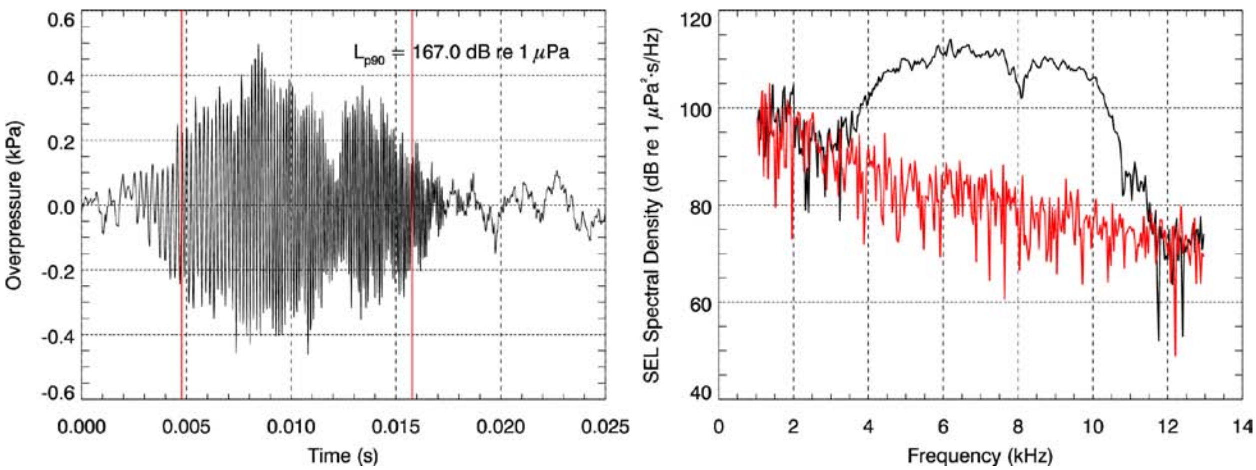

FIGURE 3.82. Sub-bottom profiler (EdgeTech 3100 SB-216S) waveform (left) and SEL spectral density over 25 ms (right) of one pulse measured at the CPA of 20 m slant range and 17 m receiver depth. The waveform has been high-pass filtered at 120 Hz. The corresponding spectral density of background noise from the preceding 25-ms window is shown in red.

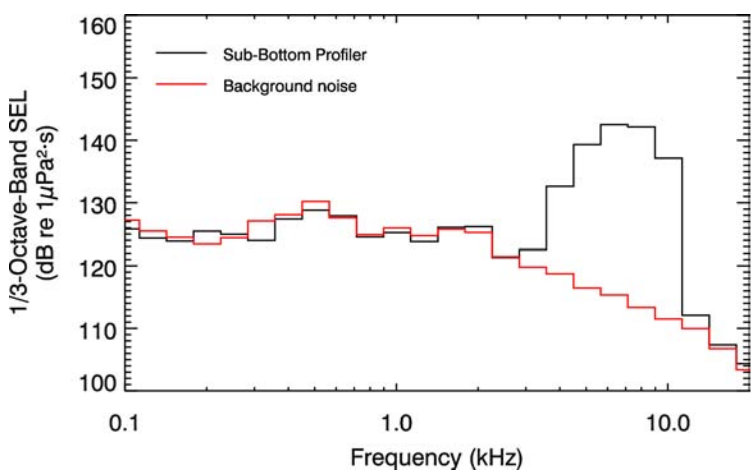

FIGURE 3.83. Sub-bottom profiler (EdgeTech 3100 SB-216S) 1/3-octave band SEL over a 25-ms time window averaged over 10 of the highest rms-amplitude pulses measured at the CPA of 20 m slant range and 17 m receiver depth. The corresponding average band levels of background noise from the 10 preceding 25-ms windows are shown in red.

Shallow Hazards Program

Harrison Bay, Beaufort Sea

Sound Speed Profile

To determine sound speed, temperature and salinity as a function of depth were measured at the SSV location with an SBE-19 Plus CTD. The CTD was lowered to the seabed (at 70°41.205'N, 150°49.111'W) immediately after deploying the OBHs on 13 Aug. The resulting temperature, salinity, and sound speed profiles are shown in Fig. 3.84.

The derived sound speed profile shows a downward refracting layer down to 7 m depth, likely due to warm fresh melt water. At depths below 7 m, the water is well mixed and the temperature, salinity, and sound speed profiles are uniform. Overall, the sound speed profile is downward refracting. Downward refracting sound speed profiles tend to increase acoustic propagation loss with range due to increased bottom loss at the seabed.

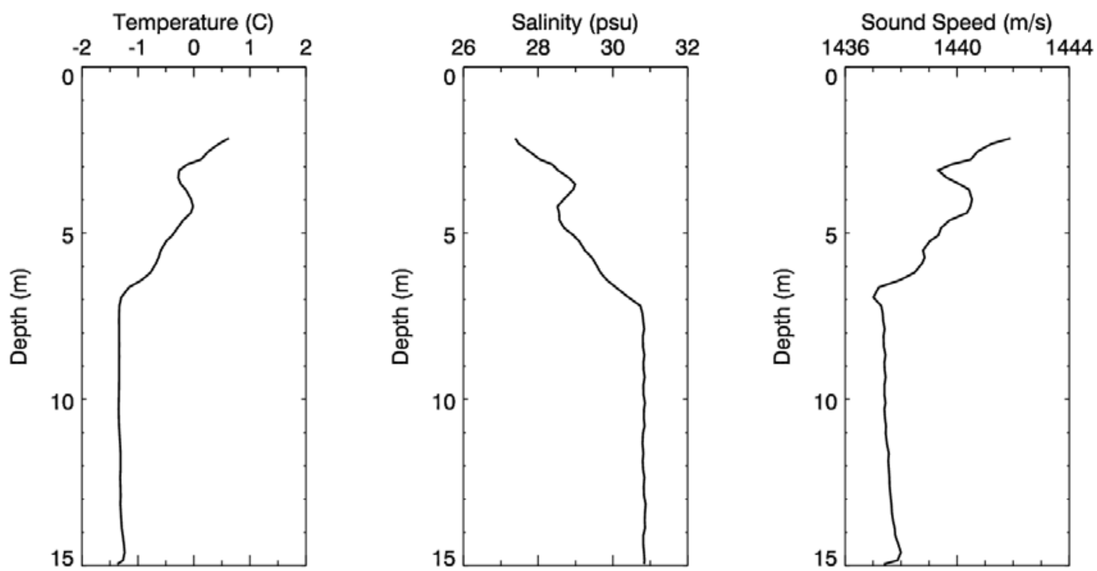

FIGURE 3.84. Temperature (left) and salinity (center) profiles measured 13 Aug at 70°41.205' N, 150°49.111' W, immediately after OBH Deployment 5, and the derived sound speed profile (right).

R/V Mt. Mitchell Self-Noise

Vessel noise produced by the *R/V Mt. Mitchell* transiting at 4 kts was measured by OBH 1 on 13 Aug during SSV track 8 (OBH Deployment 5) at 15 m water depth. Sound levels are plotted as a function of time in Fig. 3.85 to show the evolution of level increase as the vessel approached and departed the OBH. Received sound levels from the approach and departure of the *Mt. Mitchell* relative to the OBH recorders showed different trends that are likely due to differences in the levels emitted fore and aft of the vessel. We have consequently analyzed and presented these results separately for the two directions. Fig. 3.86 presents the rms levels versus range and best-fit and 90th percentile curve fits to these data. Spectrogram and power spectral density plots for CPA (9 m range) are shown in Fig. 3.87 and Fig. 3.88, respectively. Data presented in these plots were recorded from the higher sensitivity hydrophone. The ranges to the sound level thresholds for the *Mt. Mitchell* travelling at 4 kts are listed in Table 3.42.

Vessel noise produced by the *R/V Mt. Mitchell* transiting at 10 kts was measured by OBH 1 on 14 Aug during SSV track 13 (OBH deployment 5) at 15 m water depth. These measurements are also plotted as a function of time in Fig. 3.89 to show the evolution of level increase as the vessel approached the recorder. Received sound levels from the *Mt. Mitchell* transiting at 10 kts are shown in Fig. 3.90. These measurements were made while the vessel approached the OBH recorder for its retrieval. Ice presence and noise from other vessels limited the useable data to the times corresponding to source-receiver ranges between 1330 and 2100 m. The figure shows rms levels versus range with the best-fit and 90th percentile trend lines and the equations thereof. The ranges to sound level thresholds for the *Mt. Mitchell* transiting at 10 kts based on the trend lines are listed in Table 3.43. Spectrogram and power spectral density plots at the CPA of 1330 m range are shown in Fig. 3.91 and Fig. 3.92, respectively. Data presented in these plots were recorded by the higher sensitivity hydrophone.

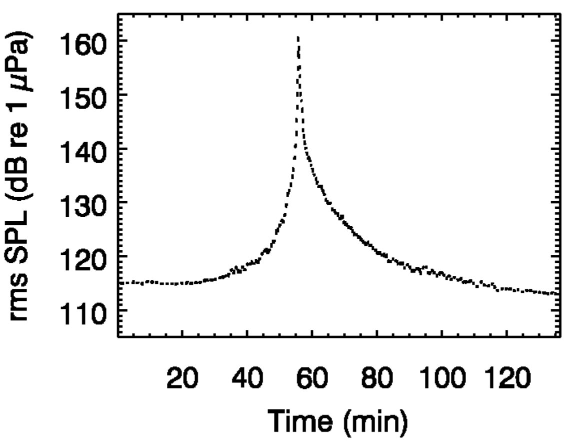

FIGURE 3.85. *Mt. Mitchell* broadband rms SPL as a function of time as the vessel approached and departed the OBH at 4 kts (12 m receiver depth). CPA was 9 m horizontal range.

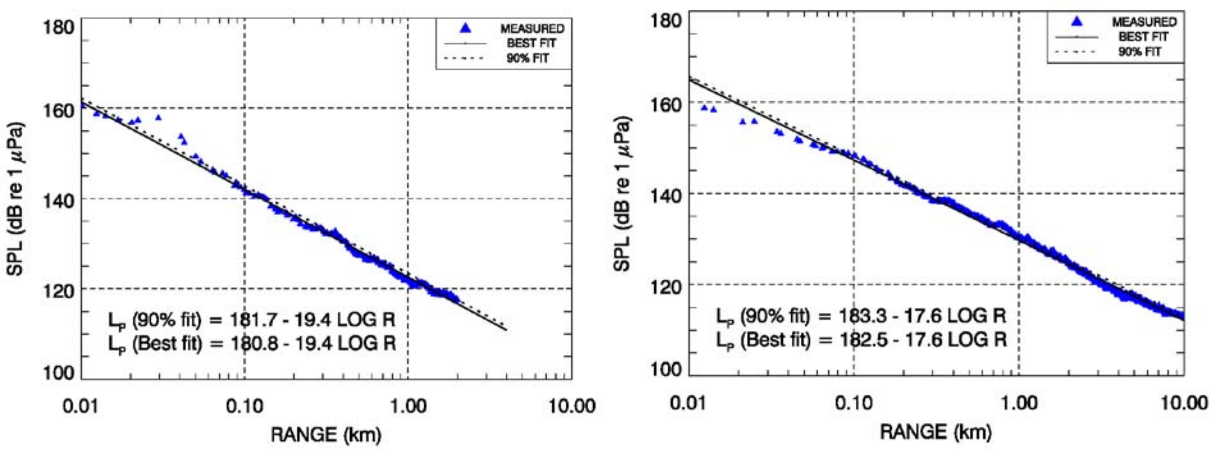

FIGURE 3.86. *Mt. Mitchell* vessel transit at 4 kts, rms SPL versus range in the forward (left) and aft (right) directions. The solid line is the least squares best fit to the rms values. The dashed line is the best-fit shifted to exceed 90% of the L_{p90} values (90th percentile fit). Data from ranges greater than 2 km were omitted since they were comparable with ambient levels.

TABLE 3.42. *Mt. Mitchell* vessel transit at 4 kts source level terms and distances to sound level thresholds (12 m receiver depth), from least-squares fit (see Fig. 3.86).

rms SPL threshold (dB re 1 μPa)	Approach (bow aspect)		Departure (stern aspect)	
	Best-fit range (m)	90th percentile fit range (m)	Best fit range (m)	90th percentile fit range (m)
190	-	-	-	-
180	<5	<5	<5	<5
170	<5	<5	5*	6*
160	12	13	19	21
150	39	43	71	78
140	130	140	260	290
130	410	460	970	1100
120	1400	1500	3600	3900
SL term (dB re 1 μPa @ 1 m)	180.8	181.7	182.5	183.3

*Extrapolated values, less than minimum measurement horizontal range of 9 m.

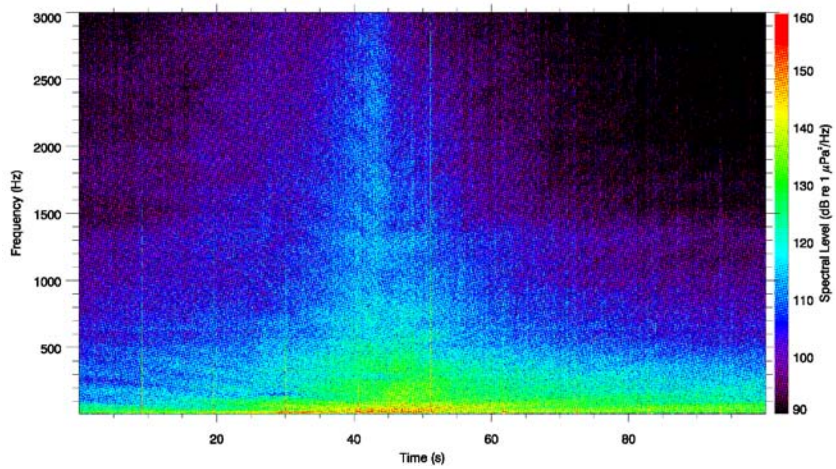

FIGURE 3.87. Spectrogram of the *Mt. Mitchell* travelling at 4 kts at CPA (9 m horizontal range). 2048-pt FFT, 48 k Hz sample-rate, Hanning window, 256-pt step size.

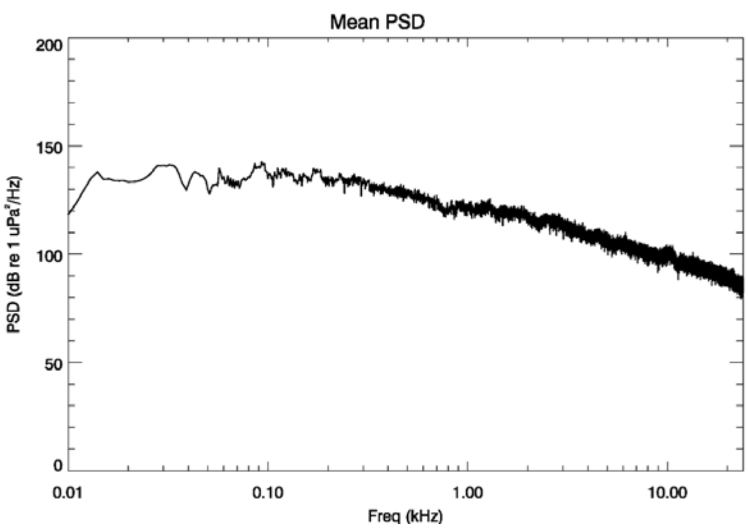

FIGURE 3.88. *Mt. Mitchell* vessel transit at 4 k ts average unfiltered Power Spectral Density (PSD) of ten 1-s windows around the 9-m CPA.

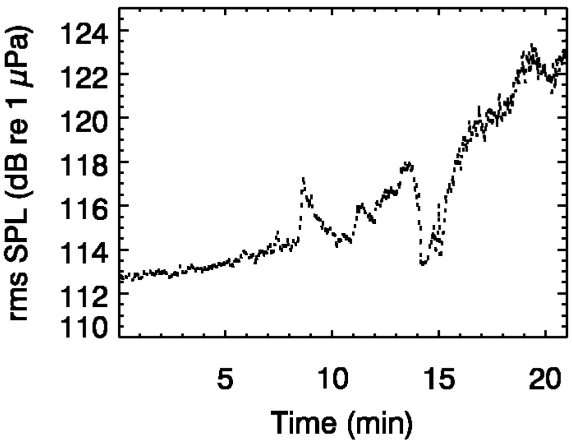

FIGURE 3.89. *Mt. Mitchell* broadband rms SPL as a function of time as the vessel approached the OBH at 10 k ts (12 m receiver depth). The closest measurement range was 1330 m.

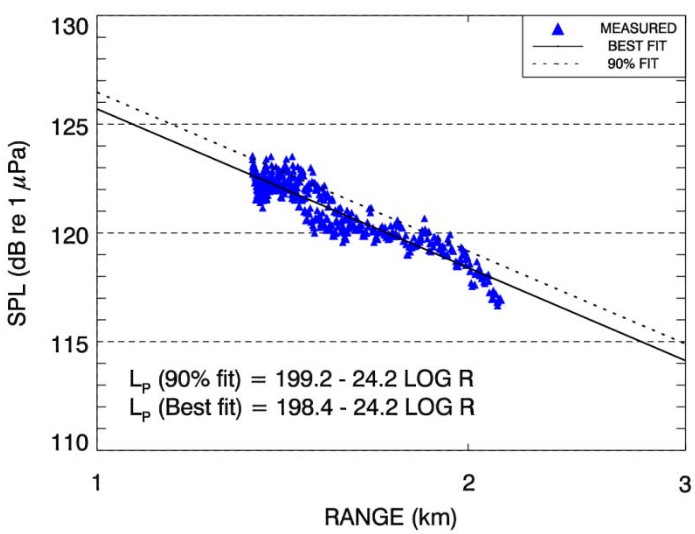

FIGURE 3.90. *Mt. Mitchell* vessel rms SPL versus range while transiting at 10 kts in the forward direction. The solid line is the least squares best fit to the rms values. The dashed line is the best fit shifted to exceed 90% of the L_{p90} values (90th percentile fit).

TABLE 3.43. *Mt. Mitchell* 10-kt transit source level terms and di stances to sound level thresholds (12 m receiver depth) determined by least-squares fit (see Fig. 3.90).

rms SPL threshold (dB re 1 µPa)	Forward of *Mt. Mitchell*	
	Best-fit range (m)	90th percentile fit range (m)
190	<10	<10
180	<10	<10
170	15*	16*
160	39*	41*
150	100*	110*
140	260*	280*
130	660*	710*
120	1700	1800
SL term (dB re 1 µPa @ 1 m)	198.4	199.2

*Less than minimum measurement range of 1330 m. These ranges are highly speculative as they are based on a small data set of much lower SPL at larger ranges. See the discussion section for more details.

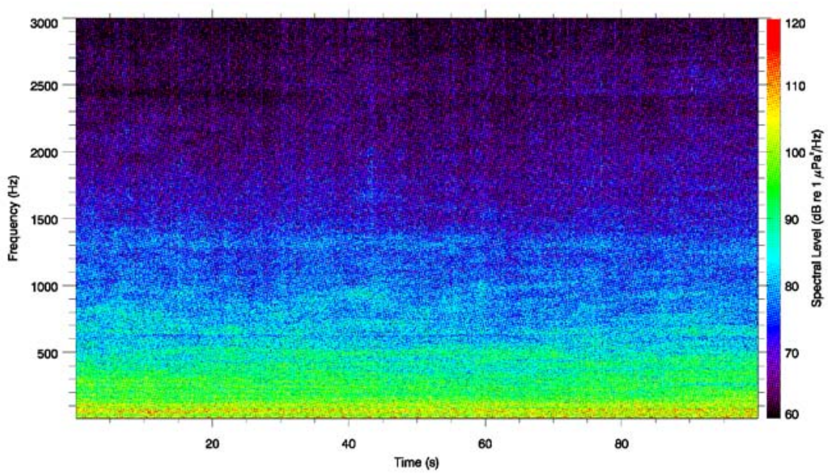

FIGURE 3.91. Spectrogram of the *Mt. Mitchell* transiting at 10 kts at the 1330-m CPA. 2048-pt FFT, 48-kHz sample rate, Hanning window, 256-pt step size.

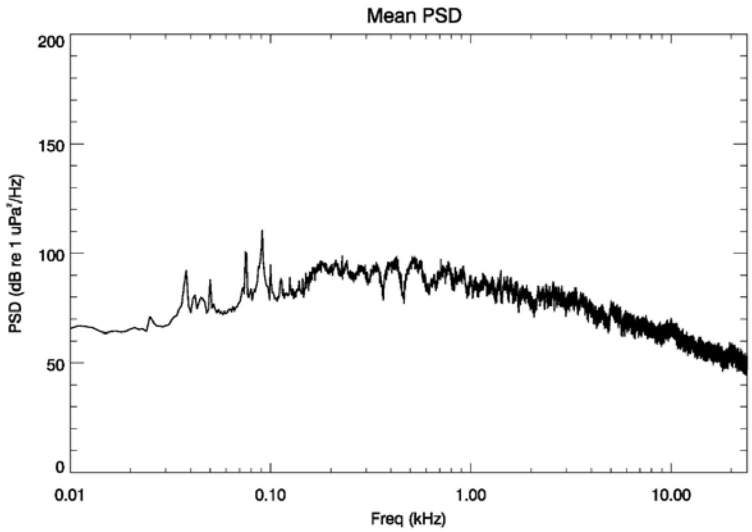

FIGURE 3.92. *Mt. Mitchell* vessel transit at 10 kts average power spectral density of ten 1-s windows at the 1330-m CPA.

Single Airgun

Underwater sound from the 10 in^3 mitigation airgun was measured during OBH Deployment 5 as the *Mt. Mitchell* towed the airgun at 2 m depth along SSV Track 9. The measurement was done on 13 Aug as the *Mt. Mitchell* approached and departed the OBH. The hydrophone was approximately 3 m above the seafloor, with 15 m nominal water depth along SSV Track 9. The CPA was 12 m slant range.

Received sound levels in the forward and aft endfire directions showed different trends and have thus been separately analyzed. Fig. 3.93 shows sound levels versus range for the forward and aft endfire directions of the 10 in^3 airgun. A curve of the form Equation 7 was fit to the data and the resulting distances to threshold levels are listed in Table 3.44.

A spectrogram of three 10 in^3 airgun pulses measured at CPA is shown in Fig. 3.94. The pulses firing rate was approximately 10 seconds. Tonal noise is from the *Mt. Mitchell*. The spectrogram shows the majority of the pulse energy is below 3 kHz.

Fig. 3.95 shows an unfiltered airgun pulse waveform and spectrum measured at 14 m slant range. The waveform shows oscillatory bubble pulses after the first break and the spectrum shows most of the energy is under 1 kHz.

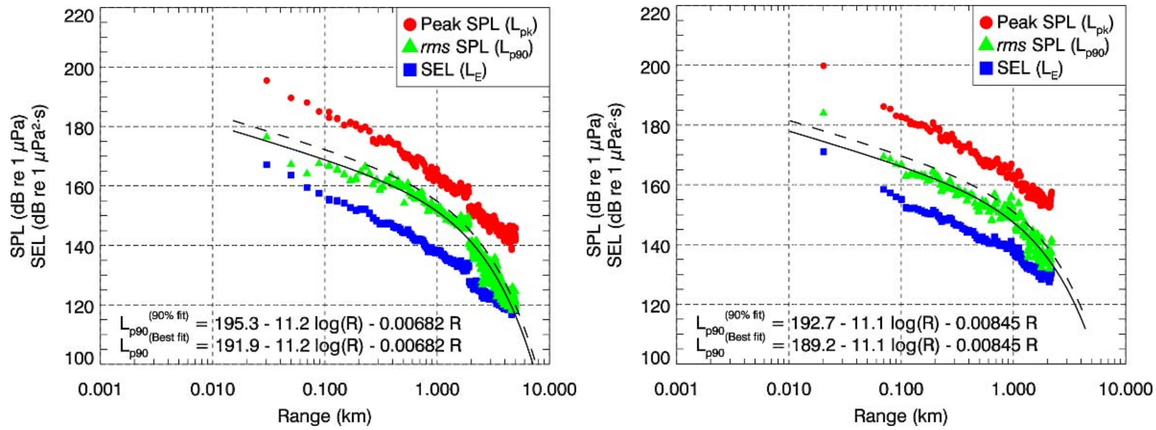

FIGURE 3.93. Single 10 in^3 airgun peak, 90% rms SPL and SEL versus range in the forward (left) and aft (right) endfire directions. Solid line is best fit of the empirical function to L_{p90} values. Dashed line is the best-fit shifted to exceed 90% of the L_{p90} values (90th percentile fit).

TABLE 3.44. Single 10 in^3 airgun source level terms and distances to sound level thresholds (12 m receiver depth) from least-squares fit (see Fig. 3.93) in the forward and aft endfire directions.

rms SPL threshold (dB re 1 µPa)	Forward endfire		Aft endfire	
	Best-fit range (m)	90th percentile-fit range (m)	Best-fit range (m)	90th percentile-fit range (m)
190	1*	3*	1**	2**
180	11*	22	7**	14**
170	80	150	49	95
160	400	600	270	420
150	1100	1400	810	1100
140	2100	2500	1600	1900
130	3300	3700	2500	2900
120	4500	5000	3500	3900
SL term (dB re 1 µPa @ 1 m):	191.9	195.3	189.2	192.7

*Extrapolated values, less than minimum measurement slant range of 14 m.
** Extrapolated values, less than minimum measurement slant range of 20 m.

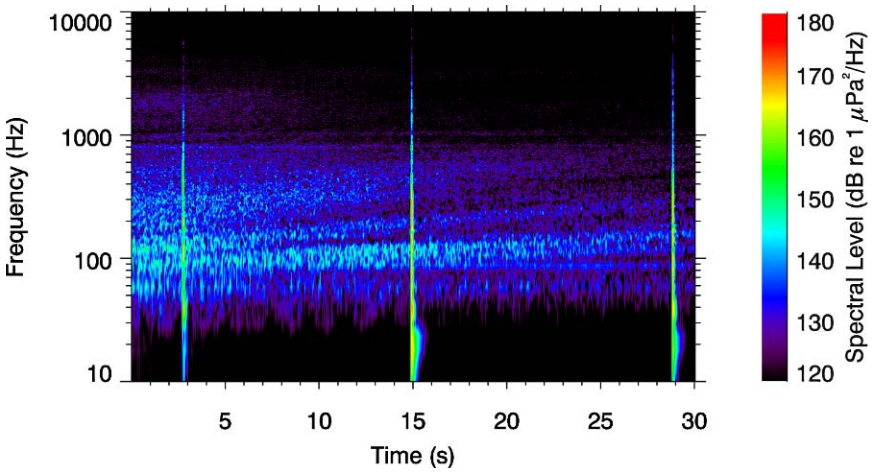

FIGURE 3.94. Spectrogram of three 10 in^3 airgun pulses at CPA slant range of 12 m. 8192-pt FFT, 48 kHz sample-rate, Hanning window, 1024-pt step size. The actual CPA occurred between the two rightmost shots.

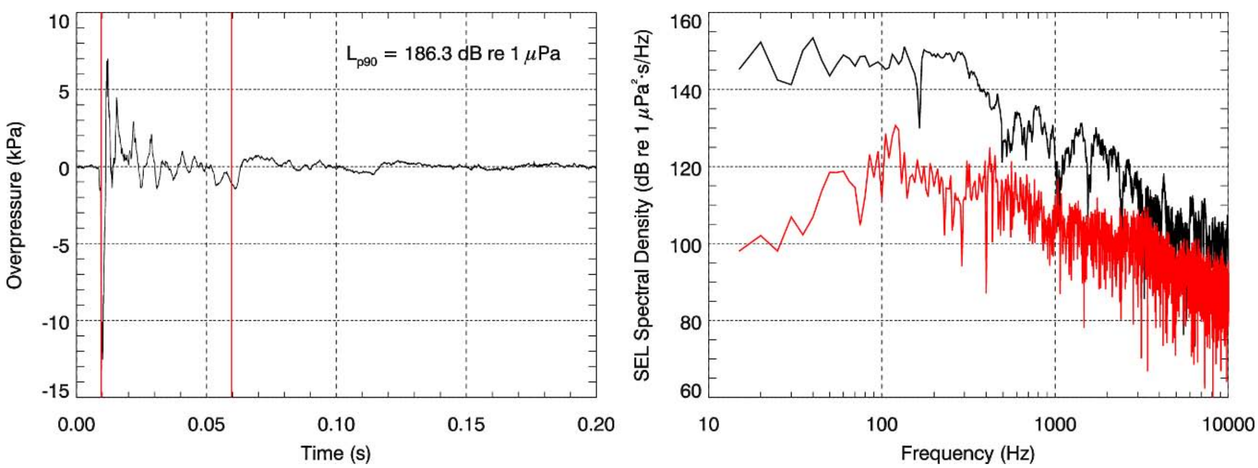

FIGURE 3.95. Single 10 in^3 airgun waveform (left) and SEL spectral density over 200 ms (right) of one pulse measured at 12 m receiver depth and 14 m slant range, approaching CPA. The corresponding spectral density of background noise from a 0.2-s window preceding the pulse is shown in red. The CPA of 12 m slant range occurred between shots.

Airgun Array

Underwater sound from the 40 in^3 airgun array was measured during OBH Deployment 5 as the *Mt. Mitchell* towed the array at 2 m depth along SSV Track 8. The measurement was done on 13 Aug as the *Mt. Mitchell* approached and departed the OBH. The hydrophone was approximately 3 m above the seafloor, with 15 m nominal water depth along SSV Track 8. The CPA was 11 m slant range.

Received sound levels in the forward and aft endfire directions showed different trends. Fig. 3.96 shows sound levels versus range for the approach and departures of the 40 in^3 airgun array. A curve of the form Equation 7 was fit to the data and the resulting distances to threshold levels are listed in Table 3.45.

A spectrogram of three 40 in^3 airgun array pulses measured at CPA is shown in Fig. 3.97. The pulses firing rate was approximately every 10 s. Tonal noise is from the *Mt. Mitchell*. The spectrogram shows the majority of the pulse energy is below 3 kHz.

Fig. 3.98 shows an unfiltered airgun pulse waveform and spectrum measured at 12 m slant range. The waveform doesn't show oscillatory bubble pulses as well as in the 10 in^3 case (see Fig. 3.95) possibly due to interference of the bubbles from the asynchronously fired airguns. The spectrum shows most of the energy is under 1 kHz.

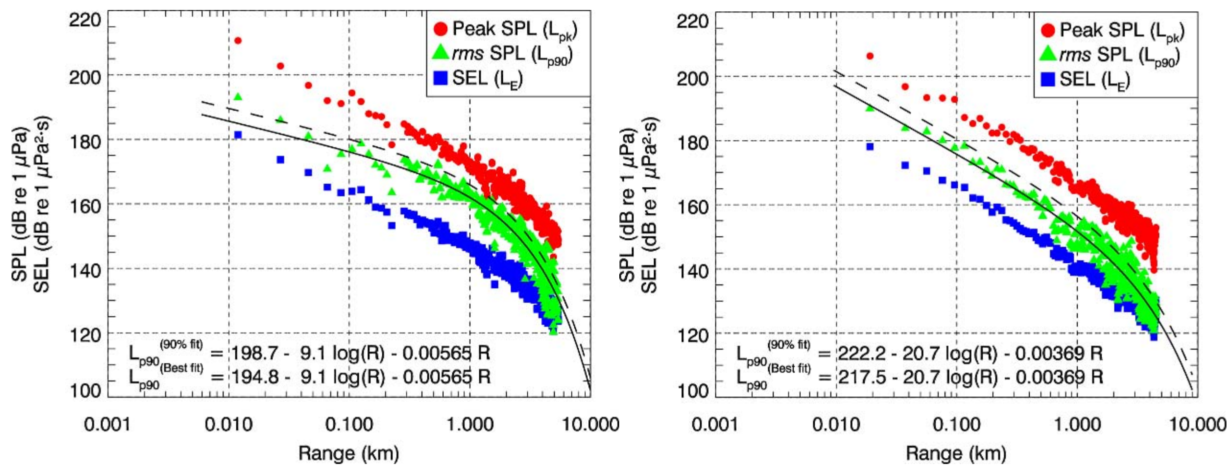

FIGURE 3.96. Airgun array (40 in^3) peak SPL, 90% rms SPL, and SEL versus range in the forward (left) and aft (right) endfire directions. Solid line is best fit of the empirical function to L_{p90} values. Dashed line is the best-fit shifted to exceed 90% of the L_{p90} values (90th percentile fit). Aft endfire data values whose ranges were greater than 4.5 km were omitted due to recorded values reaching apparent ambient levels.

TABLE 3.45. Airgun array (40 in^3) source level terms and distances to sound level thresholds (12 m receiver depth) from least-squares fit (see Fig. 3.96) in the forward and aft endfire directions.

rms SPL threshold (dB re 1 μPa)	Forward endfire		Aft endfire	
	Best-fit range (m)	90th percentile-fit range (m)	Best-fit range (m)	90th percentile-fit range (m)
190	3*	9*	21	36
180	40	100	63	110
170	340	620	180	300
160	1200	1700	490	740
150	2500	3000	1100	1600
140	3900	4500	2200	2900
130	5500	6100	3700	4500
120	7100	7700	5400	6400
SL term (dB re 1 μPa @ 1 m):	194.8	198.7	217.5	222.2

*Extrapolated value, less than minimum measurement slant range of 11 m.

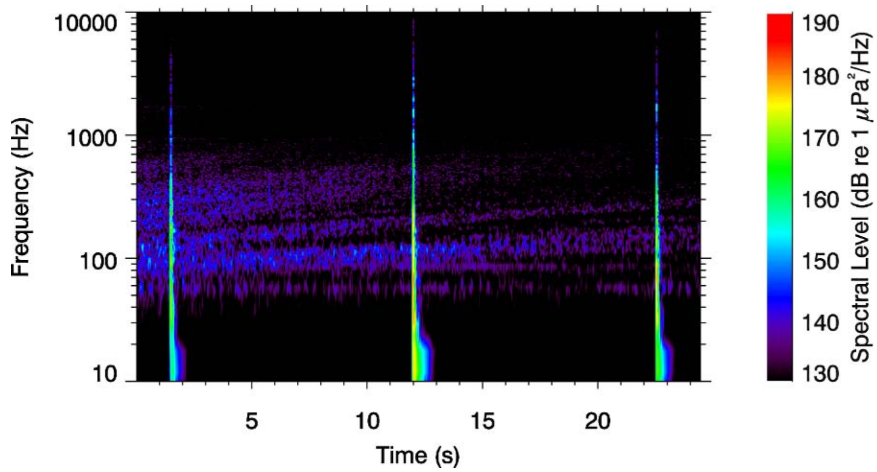

FIGURE 3.97: Spectrogram of three 40 in^3 airgun array pulses at the CPA of 11 m slant range. 8192-pt FFT, 48 kHz sample-rate, Hanning window, 1024-pt step size. CPA occurred between the two rightmost pulses.

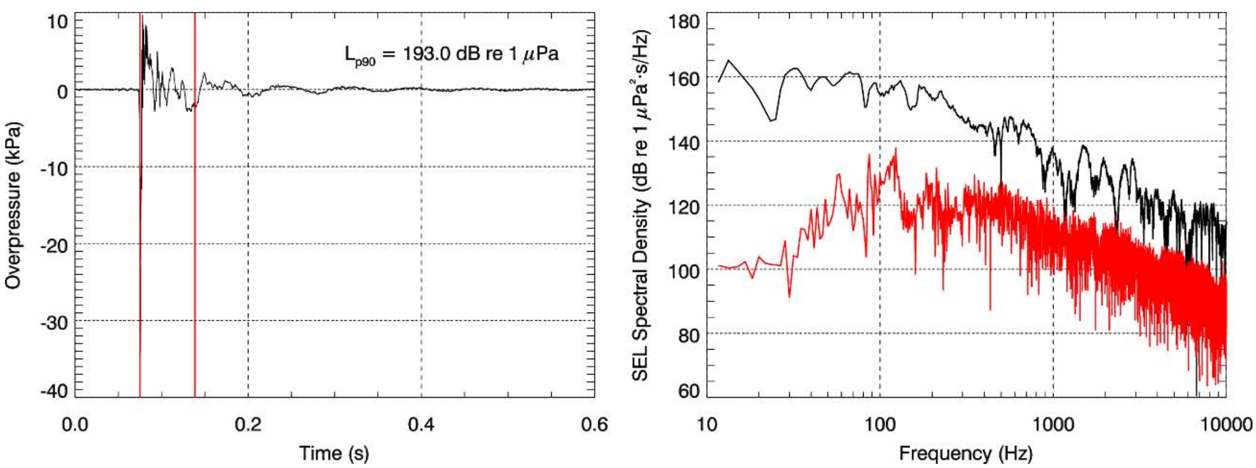

FIGURE 3.98. Airgun array (40 in^3) waveform (left) and SEL spectral density over 600 ms (right) of one pulse measured at 12 m receiver depth and 12 m slant range of, approaching CPA. The corresponding spectral density of background noise from a 0.6-s window preceding the pulse is shown in red. The CPA of 11 m slant range occurred between shots.

Sub-Bottom Profiler, Vessel-mounted

Underwater sound from the sub-bottom profiler (GeoPulse) was measured during OBH Deployment 5 as the profiler was operated along SSV Track 9. The measurement was done on 13 Aug as the profiler approached and departed the OBH. The hydrophone was approximately 3 m above the seafloor, with 15 m nominal water depth along the SSV track. The profiler was mounted 5 m below the surface and the CPA was 8 m slant range.

Fig. 3.36 shows sound levels versus range for the sub-bottom profiler in both the forward and aft endfire directions. A 1 kHz high-pass filter has been applied to the measured data. A curve of the form Equation 7 was fit to the filtered data and the resulting distances to threshold levels are listed in Table 3.26.

A spectrogram of three sub-bottom profiler pulses measured at the CPA of 8 m slant range is shown in Fig. 3.37. The pulse firing rate was approximately 15 ms. The spectrogram shows the majority of the pulse energy is between 1 and 20 kHz.

Fig. 3.38 shows a 120 Hz high-pass-filtered SBP pulse waveform and spectrum measured at the CPA of 8 m slant range. The spectrum shows the expected peak frequency at 3.5 kHz.

Fig. 3.39 shows third-octave band levels of the 10 highest rms-amplitude pulses and of the background noise from 15 ms windows preceding those pulses. The band levels are highest near the 3.5 kHz center frequency and are higher than background levels for frequencies above 1 kHz.

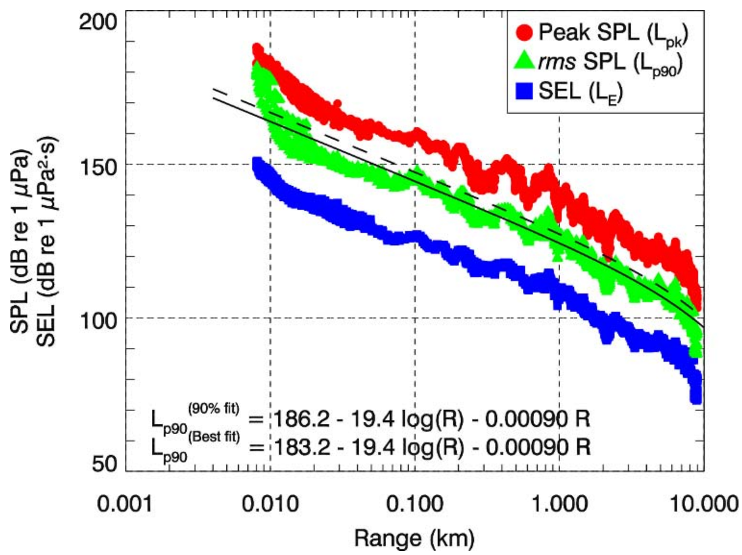

FIGURE 3.99. Sub-bottom profiler (GeoPulse) peak, 90% rms SPL and SEL versus range, 12 m measurement depth. Solid line is best fit of the empirical function to L_{p90} values. Dashed line is the best-fit shifted to exceed 90% of the L_{p90} values (90th percentile fit). Pulses beyond 9 km range were indistinguishable from background noise.

TABLE 3.46. Sub-bottom profiler (GeoPulse) source level terms and distances to sound level thresholds (12 m receiver depth) from least-squares fit (see Fig. 3.36).

rms SPL threshold (dB re 1 μPa)	Distance (m)	
	Best-fit	90th percentile-fit
190	[6]	[7]
180	1*, [8]	2*, [9]
170	5*, [10]	7*, [12]
160	16, [13]	22, [15]
150	52	73
140	170	240
130	530	740
120	1600	2100
110	4000	5000
SL term (dB re 1 μPa @ 1 m):	183.2	186.2

*Extrapolated value, less than minimum measurement slant range of 8 m.

[n] Based on a separate near-CPA analysis where the OBH is partly insonified by the main lobe of the projector, extrapolated if less than minimum measurement slant range of 8 m.

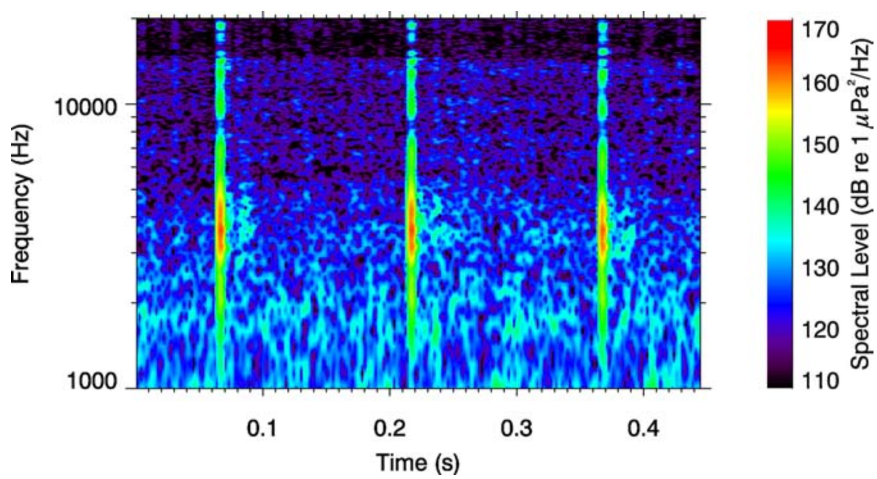

FIGURE 3.100: Spectrogram of three sub-bottom profiler (GeoPulse) pulses at CPA (8 m slant range). 512-pt FFT, 48 kHz sample-rate, Hanning window, 64-pt step size.

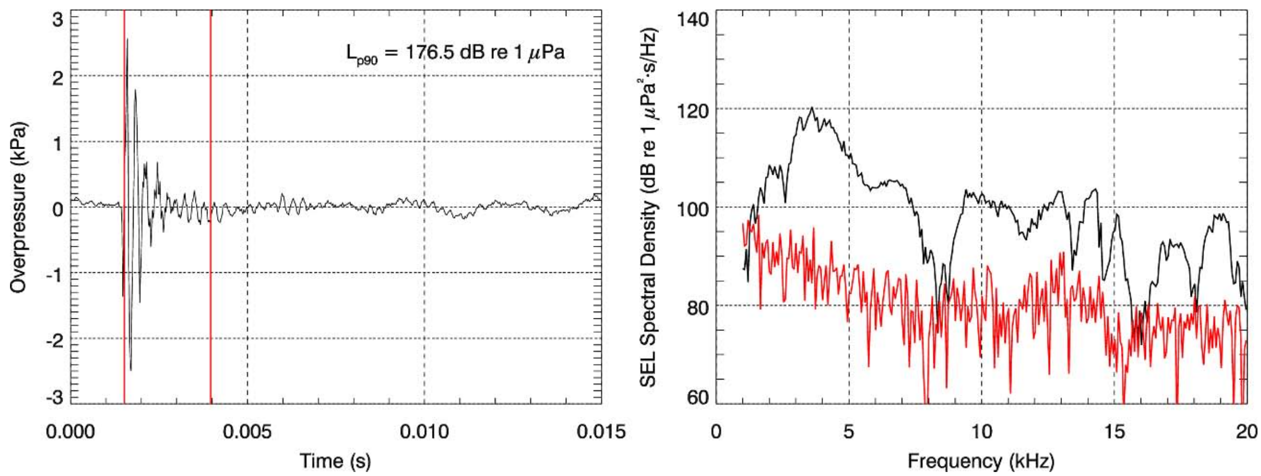

FIGURE 3.101. Sub-bottom profiler waveform (left) and SEL spectral density over 15 ms (right) of one pulse measured at the CPA of 8 m slant range and 12 m receiver depth. A high-pass filter of 120 Hz was applied.

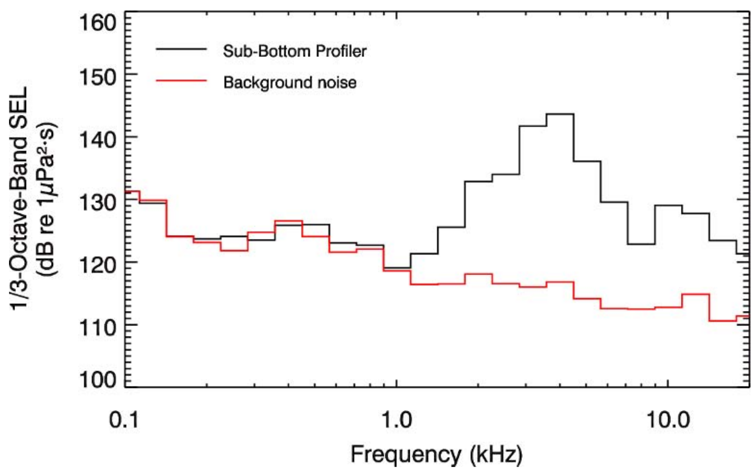

FIGURE 3.102. Sub-bottom profiler (GeoPulse) average third-octave band SEL over 15 ms time windows from 10 pulses measured at the CPA of 8 m slant range and 12 m receiver depth. The corresponding average band levels of background noise from the preceding 15 ms windows are shown in red.

<u>*Mauya Prospect, Beaufort Sea*</u>

Multibeam Sonar, Vessel-mounted

Underwater sound from the multibeam sonar (RESON SeaBat 8101) was measured from the *Arctic Seal* as the sonar was operated by the *Mt. Mitchell* along track lines 10-12 (Fig. 3.19) on 15 Sep 2010, passing 41 m, 200 m and 380 m from the recording hydrophone. The hydrophone was deployed at mid water column depth (7 m) for all acquisitions. Measurements made at the three CPAs provided in-beam sound levels at three offset distances; these were analyzed to calculate ranges to specific in-beam threshold levels, to estimate source levels, and to examine the frequency content of the sonar pulses.

The 10 highest rms-amplitude pulses from each CPA recording are shown in (Fig. 3.103) as a function of range. The pulses were band-pass filtered around the 240 kHz center frequency with 20 kHz bandwidth to omit contributions from other noise sources. Background noise levels were computed from 30 ms time windows preceding each pulse and were subtracted from the pulse levels to eliminate spurious contributions from both acoustic and electrical noise in the recordings. A curve of the form given in Equation 7 was fitted to the data, using a fixed absorption coefficient of 44.2 dB/km[7]. Distances to threshold levels were calculated from the fit and are listed in Table 3.47.

The received pulse waveforms include separate arrivals for the direct and bottom reflected acoustic propagation paths. The sound levels of just the direct-path pulses, measured at the 41 m range CPA, were analyzed to calculate the source level of the sonar. These pulses were band-pass filtered from 230 to 250 kHz and were back-propagated using 20logR spherical spreading and an absorption coefficient of 44.2 dB/km. The mean received levels of the direct-path arrival and the derived source levels are listed in Table 3.48.

Fig. 3.104 shows a spectrogram of three of the SeaBat 8101 multibeam sonar pulses. The pulse repetition rate was approximately 1 per 57 ms with a nominal pulse duration of 23 ms. The first harmonic of the multibeam pulses are also visible at 480 kHz. The saw-tooth patterns are inducted electrical noise and are not acoustic in origin. Two side-scan sonar pulses are also visible at 120 and 400 kHz.

Fig. 3.105 shows an unfiltered direct path arrival waveform, spectrum, and background spectrum. The pulse spectrum peaks at the 240 kHz center frequency about 40 dB higher than background levels and also has a secondary component at 480 kHz, 20 dB above background levels, which is the first harmonic of the 240 kHz center frequency. Background levels increase near the 240 kHz center frequency due to inducted electrical noise.

Fig. 3.106 shows the subsequent bottom-scattered arrival waveform, spectrum, and background spectrum. Peaks in the background spectrum at 120 kHz and in the 380-400 kHz frequency range are from concurrent side-scan sonar pulses. Peaks in the 300-310 and 450-465 kHz frequency range are from inducted electrical noise.

Third-octave band levels were calculated for the ten strongest multibeam sonar pulses and for the background noise from 25 ms windows preceding the pulses. The band levels were averaged over all ten windows and are shown in Fig. 3.107. Levels in the 125 kHz band are higher than background levels because of concurrent side-scan sonar pulses.

[7] Absorption loss at 240 kHz calculated based on GDEM monthly mean temperature and salinity for Sep at the track line location (Carnes 2009, Teague et al. 1990).

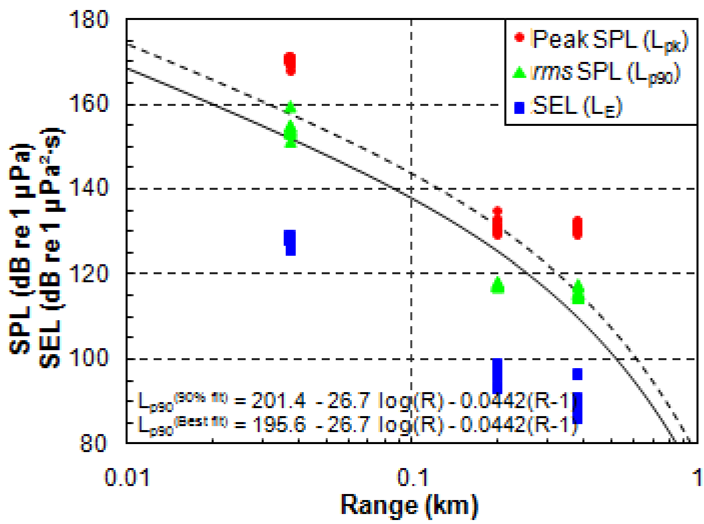

FIGURE 3.103. Multibeam sonar (RESON SeaBat 8101) 240-kHz pulse in-beam peak SPL, 90% rms SPL, and SEL versus range, at 7 m receiver depth. Solid line is best fit of the empirical function to L_{p90} values. Dashed line is the best-fit shifted to exceed 90% of the L_{p90} values (90th percentile fit). Measurements at 200 and 380 m range are at near background noise levels of these recordings.

TABLE 3.47. Multibeam sonar (RESON SeaBat 8101) 240-kHz pulse in-beam source level terms and distances to sound level thresholds (7 m receiver depth) from least-squares fit (see Fig. 3.103).

rms SPL threshold (dB re 1 µPa)	Distance (m)	
	Best-fit	90th percentile-fit
190	2	3
180	4	6
170	9	14
160	20	32
150	43	66
140	87	120
130	160	210
120	260	330
SL term (dB re 1 µPa @ 1 m):	195.6	201.4

TABLE 3.48. Multibeam sonar (RESON SeaBat 8101) 240-kHz pulse average received sound levels of 10 direct path arrival pulses, measured at 40 m range and 7 m receiver depth, and source levels derived by 20log*R* back-propagation with absorption coefficient 44.2 dB/km.

	Range (m)	Peak SPL (dB re 1 µPa)	rms SPL (dB re 1 µPa)	SEL (dB re 1 µPa2·s)
Mean received level	40	170.5	166.9	127.5
SL	1	203.5	199.9	160.5

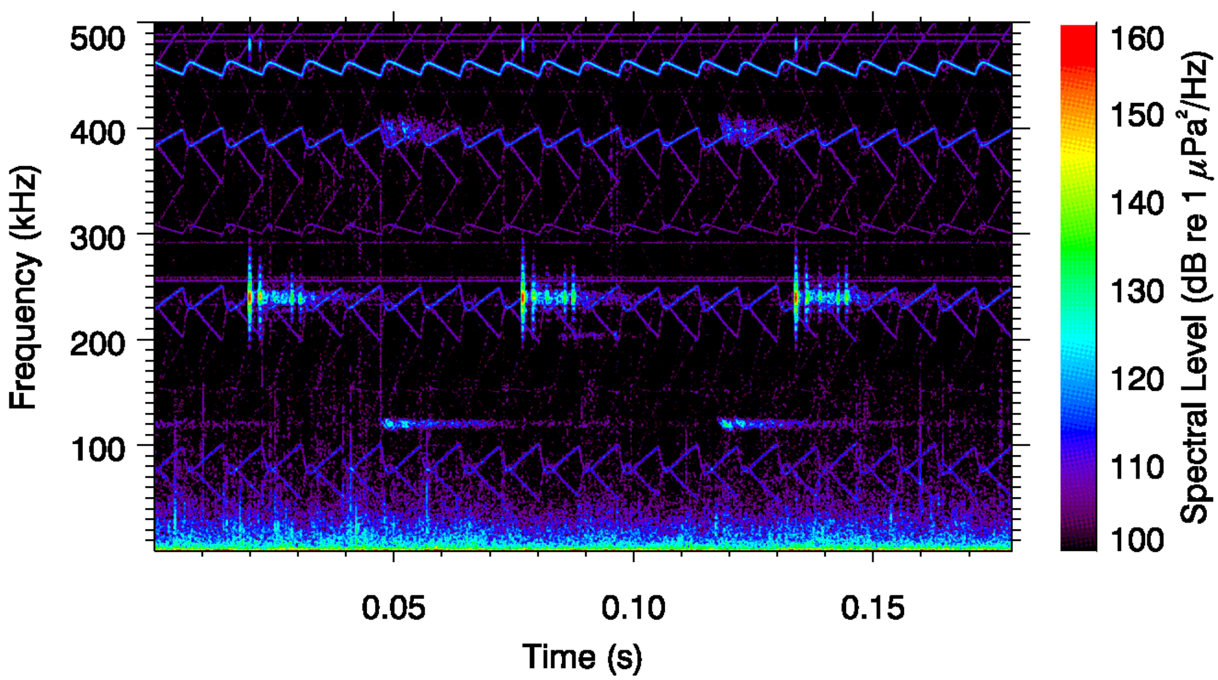

FIGURE 3.104. Spectrogram of three multibeam sonar pulses (RESON SeaBat 8101) measured at 41 m range and 7 m receiver depth. 1024-pt FFT, 1 MHz sample-rate, Hanning window, 128-pt step size. The saw-tooth patterns are inducted electrical noise. Two side-scan sonar pulses are also visible at 120 and 400 kHz, as well as the first harmonic of the multibeam sonar at 480 kHz.

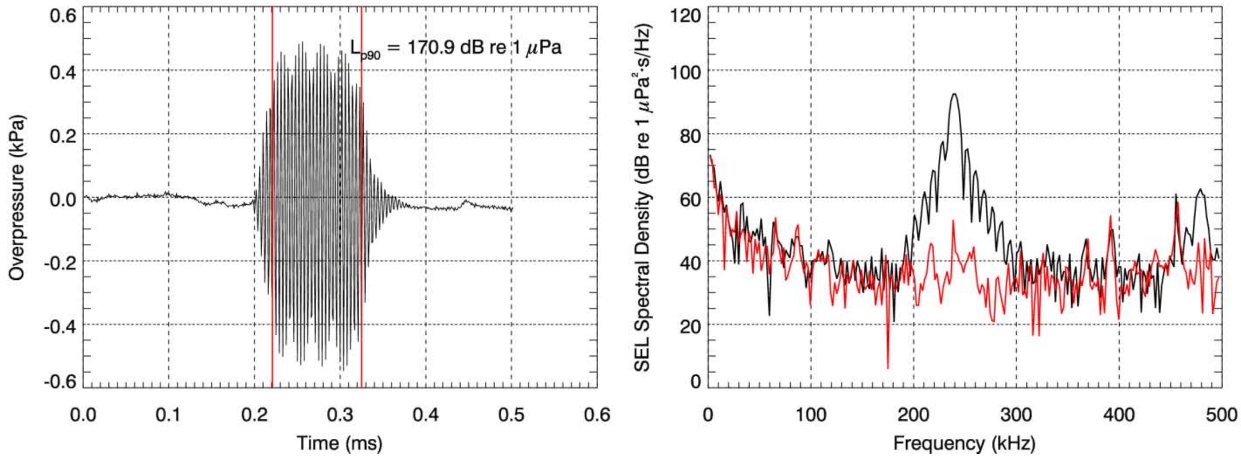

FIGURE 3.105. Multibeam sonar (RESON SeaBat 8101) waveform (left) and SEL spectral density over 0.5 ms (right) of one direct path pulse arrival measured at 40 m range and 7 m receiver depth. The corresponding spectral density of background noise from the preceding 0.5 ms window is shown in red.

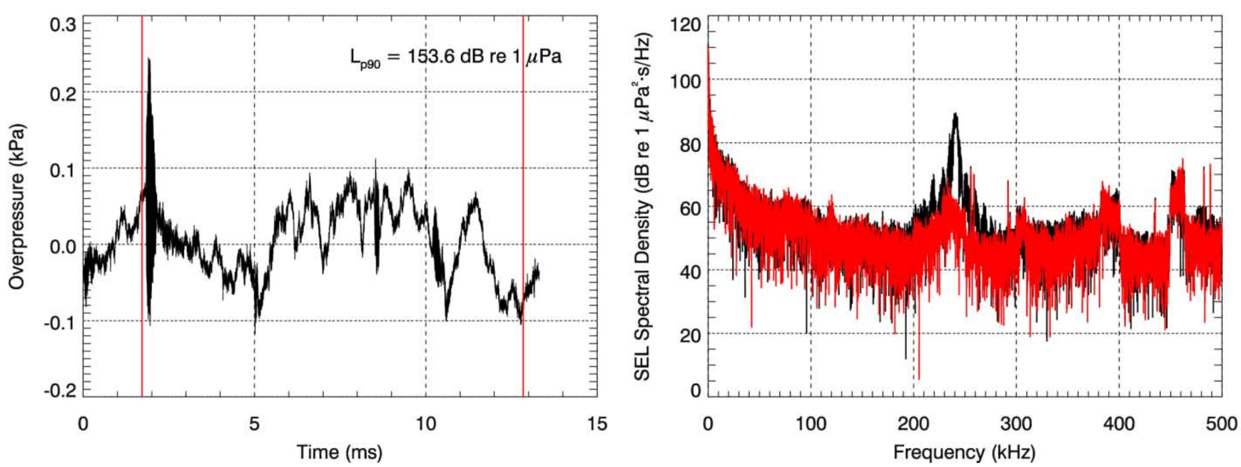

FIGURE 3.106. Multibeam sonar (RESON SeaBat 8101) waveform (left) and SEL spectral density over 13.2 ms (right) of the bottom-scattered pulse arrival (excluding the direct path arrival) measured at 40 m range and 7 m receiver depth. The corresponding spectral density of background noise from a 13.2 ms window preceding the direct path arrival is shown in red.

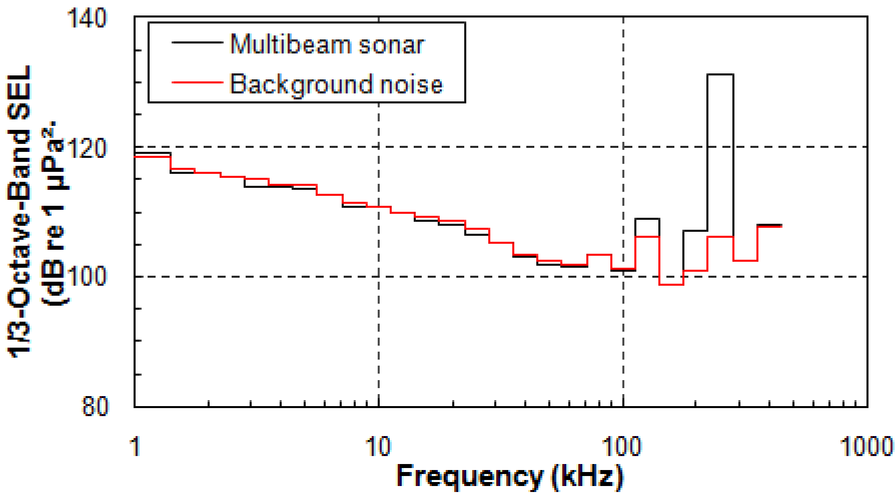

FIGURE 3.107. Multibeam sonar (RESON SeaBat 8101) average 1/3-octave band SEL over 25 ms time windows from 10 pulses measured at 40 m range and 7 m receiver depth. The corresponding average band levels of background noise from the preceding 25 ms windows are shown in red.

Single-Beam Sonar, Vessel-mounted

Underwater sound from the single-beam sonar (Odom Echotrac CVM) was measured using the *Arctic Seal* as a recording platform while the sonar was operated by the *Mt. Mitchell* along SSV Tracks 10–12 (Fig. 3.19) on 15 Sep. The CPAs of the single-beam sonar were 51, 200, and 380 m from the mean receiver location. The hydrophone was deployed at mid water column depth (7 m) for all acquisitions. Measurements made at the three CPAs notionally provided in-beam sound levels; only pulses from the 51-m CPA, however, were detectable above background noise. This is likely due to the strong vertical directivity of this source. Consequently, only pulses from the 51-m CPA measurement were analyzed to estimate the source level and to examine the frequency content of the sonar pulses.

The sound levels of the 10 highest rms-amplitude pulses at the 51-m CPA were band-pass filtered from 200 to 210 kHz and were back-propagated using 20log*R* spherical spreading and an absorption coefficient of 37 dB/km[8] to estimate the source level. The mean received levels of the pulses and source level are listed in Table 3.49.

Fig. 3.108 shows a spectrogram of three single-beam sonar pulses. The pulse repetition rate was approximately 10 per second with nominal pulse duration of 20 ms. The spectrogram also contains periodic patterns from inducted electrical noise.

FIGURE 3.109 shows an unfiltered pulse waveform, spectrum, and background spectrum. The pulse is obscured by background noise in the waveform plot, but the spectrum shows a peak at 205 kHz that is 10 dB above background levels. The increases in background levels at 240, 300, and 400 kHz arise respectively from the multibeam sonar, inducted electrical noise, and the side-scan sonar.

Third-octave band levels were calculated for the 10 strongest single-beam pulses and of the background noise from 30 ms windows preceding the pulses. The band levels were averaged over all ten

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[8] Absorption loss at 205 kHz calculated based on GDEM monthly mean temperature and salinity for Sep at the track line location (Carnes 2009, Teague et al. 1990).

windows and are shown in Fig. 3.110. Levels in the 200 kHz band exceed background levels by 5 dB. Levels in the 125 and 260 kHz bands exceed background levels due to concurrent side-scan and multibeam sonar pulses, respectively.

TABLE 3.49. Single-beam sonar (Odom Echotrac CVM) 205 kHz pulse average received sound levels of 10 pulses, measured at 51 m range and 7 m receiver depth, and source levels derived by 20logR back-propagation with absorption coefficient 37 dB/km.

	Range (m)	Peak SPL (dB re 1 µPa)	rms SPL (dB re 1 µPa)	SEL (dB re 1 $\mu Pa^2 \cdot s$)
Mean received level	51.4	139.1	114.5	98.1
Estimated source level	1	175.2	150.5	134.2

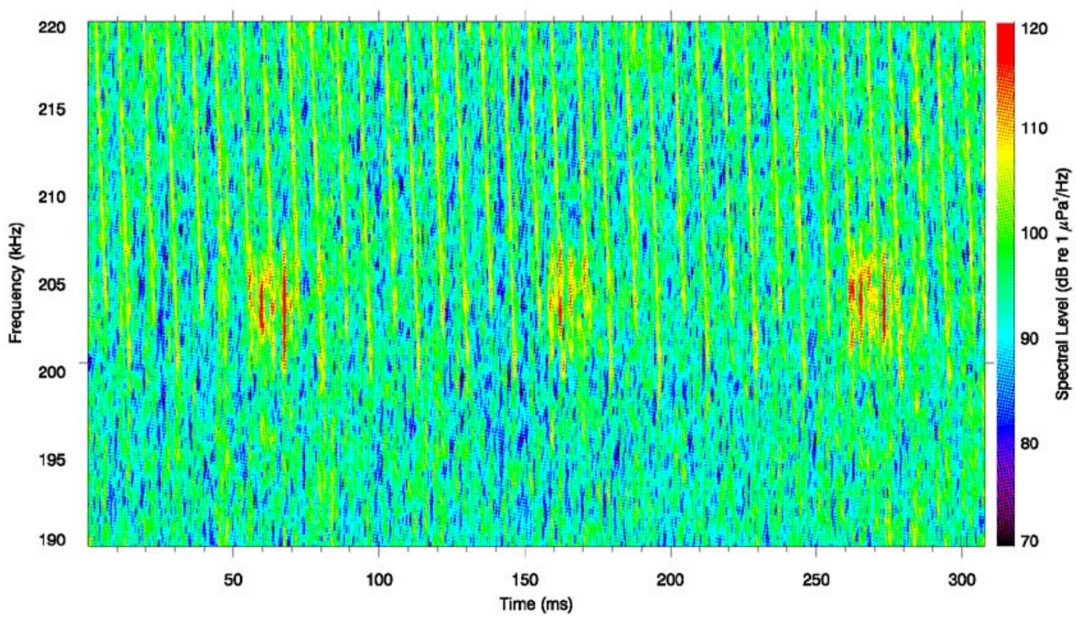

FIGURE 3.108. Spectrogram of three single-beam sonar (Odom Echotrac CVM) pulses measured at 51 m range and 7 m receiver depth. 2048-pt FFT, 1 MHz sample-rate, Hanning window, 256-pt step size. The periodic background patterns are inducted electromagnetic noise and are not part of the acoustic signal.

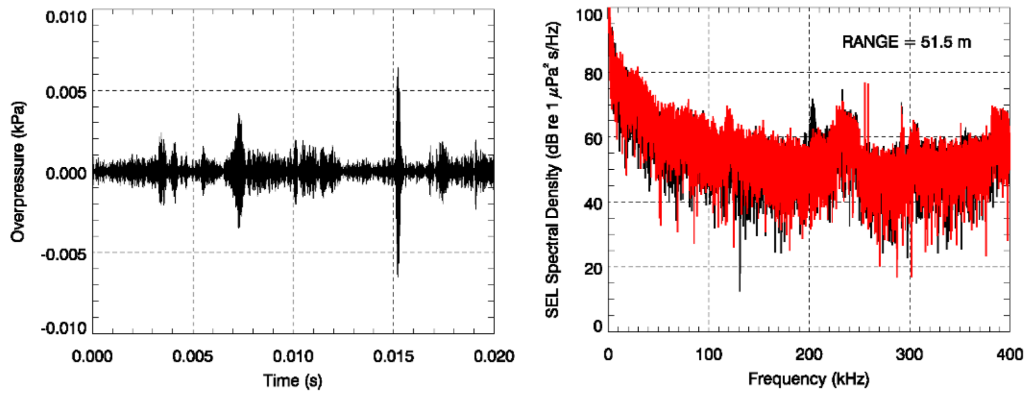

FIGURE 3.109. Single-beam sonar (Odom Echotrac CVM) waveform filtered from 190 – 210 kHz (left) and SEL spectral density over 20 ms (right) of one pulse measured at the 51-m CPA, 7 m receiver depth. The corresponding spectral density of background noise from the preceding 20 ms window is shown in red.

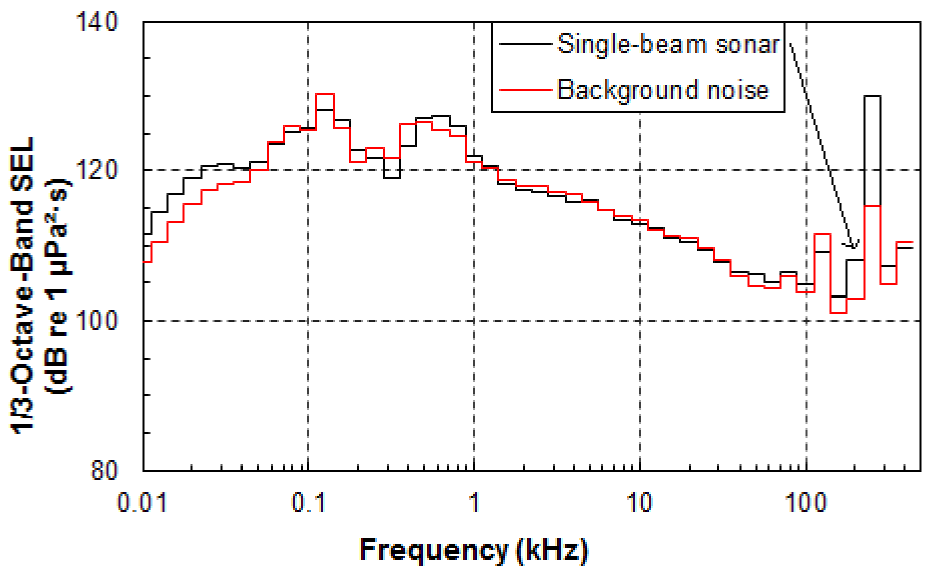

FIGURE 3.110. Single-beam sonar (Odom Echotrac CVM) average 1/3-octave-band in-beam SEL over 30-ms time windows from 10 pulses measured at 51 m range and 7 m receiver depth. The corresponding average band levels of background noise from the preceding 30 ms windows are shown in red. The arrow points to the single-beam sonar band (200 kHz). Levels in the 125- and 260-kHz bands exceed background levels due to concurrent side-scan and multibeam sonar pulses, respectively.

Side-Scan Sonar, Towfish

The side-scan sonar (EdgeTech 4200-MP Dual Frequency towfish, operating at 120 and 400 kHz) was measured during High-Frequency Measurement 4 from the *Arctic Seal* at a hydrophone depth of 7 m as the sonar was towed by the *Mt. Mitchell* along three 2 km long parallel track lines on 15 Sep (SSV Tracks 10–12). The CPAs of the side-scan sonar were 42, 194, and 385 m from the mean receiver location.

To compute absolute received sound levels and source levels, the 120-kHz pulses were band-pass filtered from 110 to 130 kHz, and the 400-kHz pulses, from 380 to 420 kHz. The signal-to-noise ratio is low due to inducted electrical interference; the background noise component was therefore computed as the average in-band level from a 10 ms time window immediately preceding each pulse and subtracted from the corresponding pulse levels.

Sound levels of the side-scan sonar as a function of time along the 42-m CPA track line are shown in Fig. 3.111 and Fig. 3.112 for the 120- and 400-kHz pulses respectively. Both the direct-path pulse arrivals and the direct- and multi-path arrivals combined are shown. In-beam levels at the CPA occur at the 46 s time mark in the graphs.

The directivity of the side-scan sonar is shown in Fig. 3.113 which presents the computed source level (at 1 m) as a function of beam angle along the 42-m CPA track line. Source levels were derived from direct-path received levels by 20log*R* back-propagation with absorption coefficients of 24 dB/km at 120 kHz and 92.1 dB/km at 400 kHz[9]. The 120-kHz directivity pattern exhibits at least five side-lobes, and the 400-kHz pattern, at least two.

Sound levels as a function of range are shown in Fig. 3.114 and Fig. 3.115 for the 120- and 400-kHz pulses, respectively. In-beam levels are those of the 15 highest rms-amplitude pulses of each track line, and out-of-beam levels are those at beam angles greater than 20°. No 400-kHz pulses are detectable from the 385-m CPA track line, during which the background noise rms SPL is 117 dB re 1 μPa in the 380–420 kHz band. The source level and ranges to sound level thresholds were determined by transmission loss curves fitted to these data, again with absorption coefficients of 24 dB/km at 120 kHz and 92.1 dB/km at 400 kHz (Table 3.50 and Table 3.51). Because out-of-beam measurements were unavailable over sufficient range for a reasonable curve-fit, the geometric spreading term of the transmission loss function was set to that of the in-beam curve fit (12.8 and 16.4 for the 120- and 400-kHz pulses, respectively), so the source level was the only fitted parameter.

Source levels for the side-scan sonar were estimated also from the average sound levels of the 10 highest rms-amplitude pulses by 20log*R* back-propagation (spherical spreading) assuming absorption coefficients of 24 dB/km at 120 kHz and 92.1 dB/km at 400 kHz (Table 3.52).

A full frequency range spectrogram of three side-scan sonar pulses, which also contains four multibeam sonar pulses and three single-beam sonar pulses, is shown in Fig. 3.116. The saw-tooth patterns are inducted electrical noise. The 120-kHz pulse sweeps from 125 to 115 kHz over 2 ms, and the 400-kHz pulse sweeps from about 410 to 385 kHz over 2 ms. A lower amplitude signal is apparent at 280 kHz, and two weaker signals at 240 and 480 kHz. The pulse repetition rate is about 14.3 per second (1 pulse every 70 ms). The waveform and spectral density of a single side-scan sonar pulse are shown in Fig. 3.117.

Third-octave band SELs of the side-scan sonar were calculated over 10 ms time windows of the 10 highest rms-amplitude pulses. The average band levels are shown in Fig. 3.118 along with the average band levels of background noise over the 10 ms time windows immediately preceding the pulse windows. The two main pulses appear in the bands centered at 125.9 and 398.1 kHz, and the intermediate frequency signals at 251 and 316 kHz. No frequency components from the side-scan sonar are evident below the 126-kHz band.

[9] Absorption loss at 120 and 400 kHz calculated based on GDEM monthly mean temperature and salinity for Sep at the track line location (Carnes 2009, Teague et al. 1990).

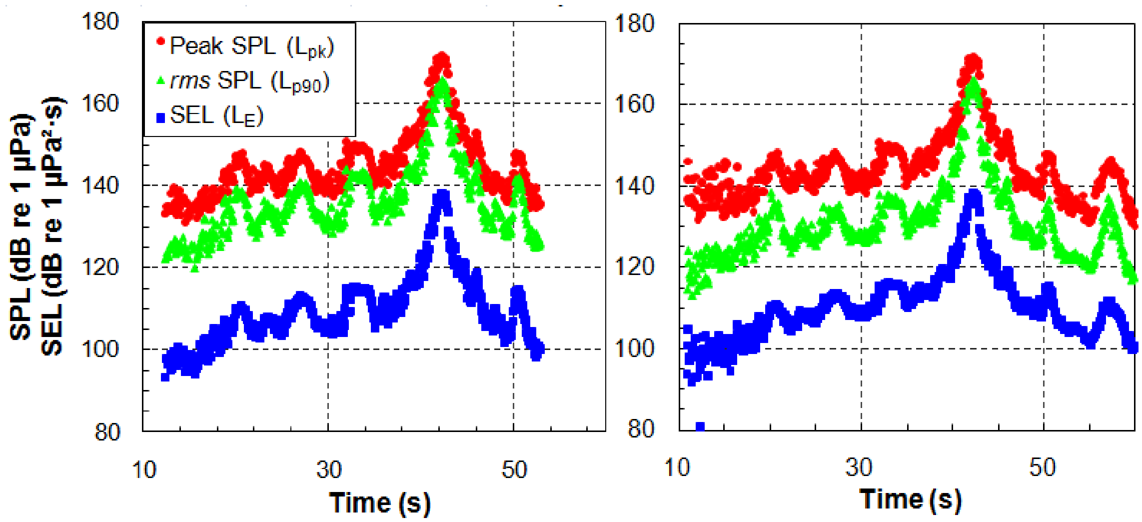

FIGURE 3.111. Side-scan sonar (EdgeTech 4200-MP Dual Frequency) 120-kHz pulse peak SPL, 90% rms SPL, and SEL over time for direct-path (left) and multi-path (right) arrivals along the 42-m CPA track line, measured at 7 m receiver depth. In-beam measurement occurs at 46 s.

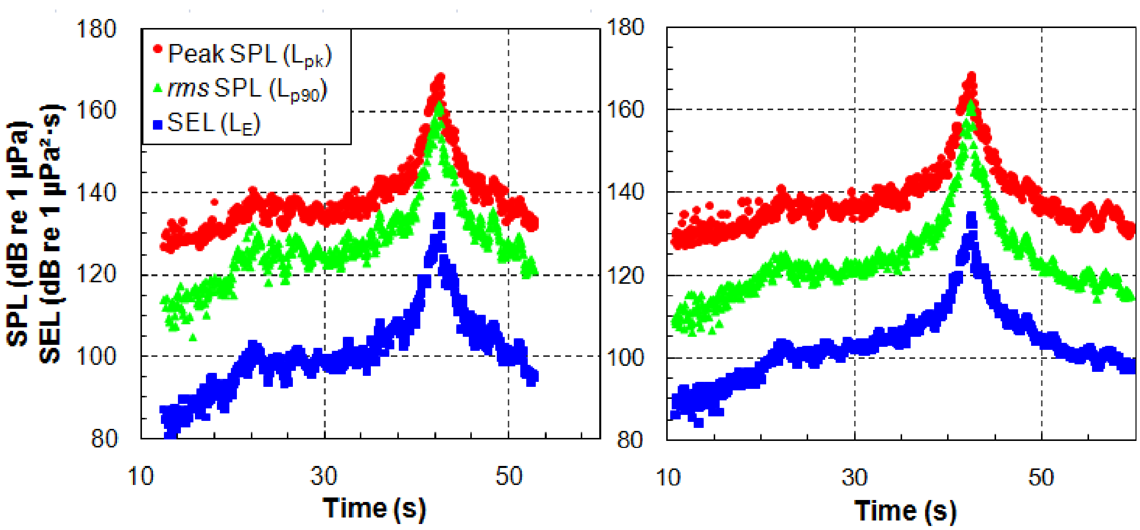

FIGURE 3.112. Side-scan sonar (EdgeTech 4200-MP Dual Frequency) 400-kHz pulse peak SPL, 90% rms SPL, and SEL over time for direct-path (left) and multi-path (right) arrivals along the 42-m CPA track line, measured at 7 m receiver depth. In-beam measurement occurs at 46 s.

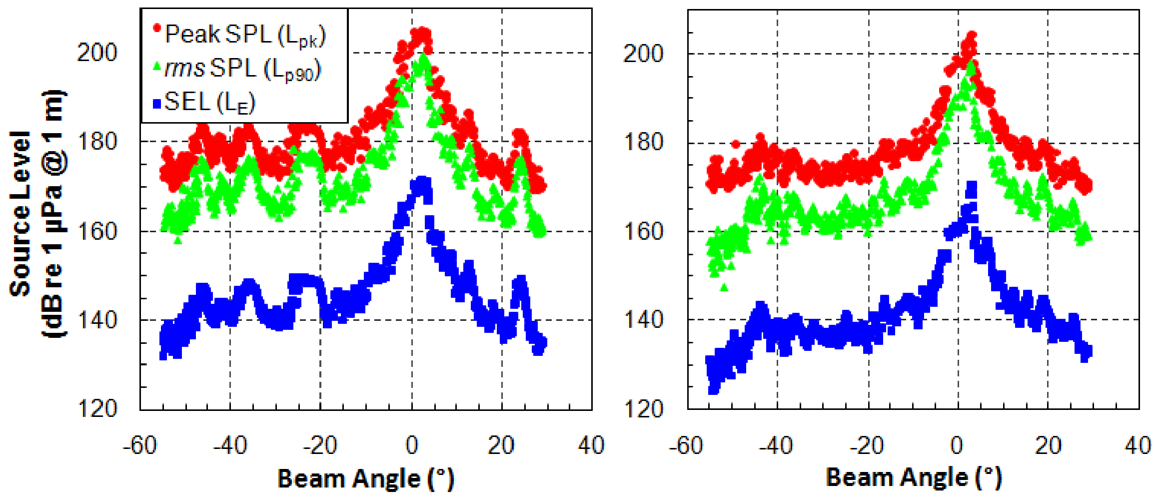

FIGURE 3.113. Side-scan sonar (EdgeTech 4200-MP Dual Frequency) source level of 120 kHz (left) and 400 kHz (right) pulses versus beam angle along the 42-m CPA track line, measured at 7 m receiver depth. Source levels were derived from direct-path arrival levels by 20log*R* back-propagation with absorption coefficients of 24 dB/km at 120 kHz and 92.1 dB/km at 400 kHz.

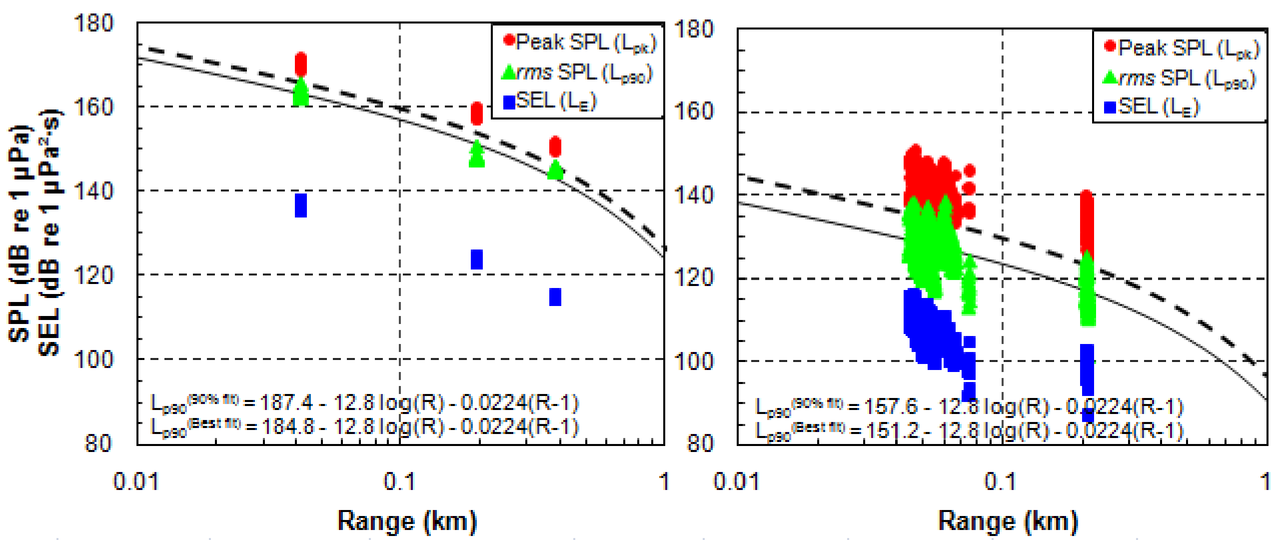

FIGURE 3.114. Side-scan sonar (EdgeTech 4200-MP Dual Frequency) 120-kHz pulse in-beam (left) and out-of-beam (right, >20° incidence angle) peak SPL, 90% rms SPL, and SEL versus range, measured at 7 m receiver depth. Solid line is best fit of the empirical function to L_{p90} values. Dashed line is the best-fit shifted to exceed 90% of the L_{p90} values (90th percentile fit).

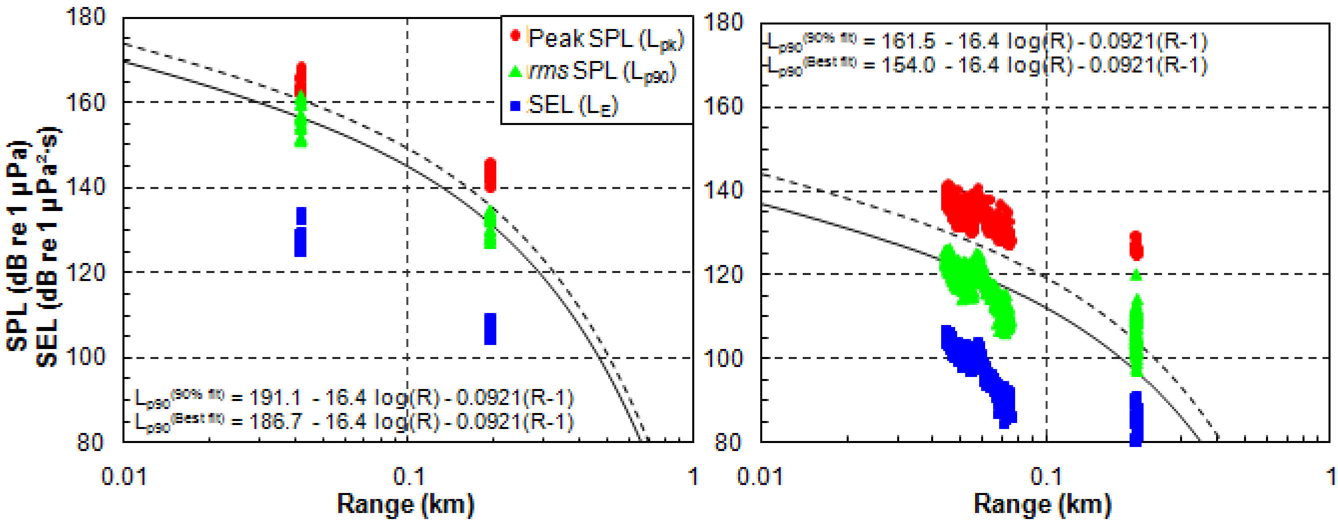

FIGURE 3.115. Side-scan sonar (EdgeTech 4200-MP Dual Frequency) 400-kHz pulse in-beam (left) and out-of-beam (right, >20° incidence angle) peak SPL, 90% rms SPL, and SEL versus range, measured at 7 m receiver depth. Solid line is best fit of the empirical function to L_{p90} values. Dashed line is the best-fit shifted to exceed 90% of the L_{p90} values (90th percentile fit).

TABLE 3.50. Side-scan sonar (EdgeTech 4200-MP Dual Frequency) 120-kHz pulse source level terms and distances to sound level thresholds (7 m receiver depth) from least-squares fit (see Fig. 3.114), in the in-beam and out-of-beam directions.

rms SPL threshold (dB re 1 μPa)	In-beam (~0° incidence angle)		Out-of-beam (>20° incidence angle)	
	Best-fit	90^{th} percentile-fit	Best-fit	90^{th} percentile-fit
190	-	-	-	-
180	3	4	-	-
170	14	22	-	-
160	67	95	-	-
150	220	280	2	4
140	470	550	8	22
130	790	880	39	98
120	1100	1200	150	280
SL term (dB re 1 μPa @ 1 m):	184.8*	187.4*	151.2*	157.6*

* These SL terms are derived from the long-range curve fits. They differ from the nearfield source levels presented in this report that were computed by back-propagating the levels measured only near CPA.

TABLE 3.51. Side-scan sonar (EdgeTech 4200-MP Dual Frequency) 400-kHz pulse source level terms and distances to sound level thresholds (7 m receiver depth) from least-squares fit (see Fig. 3.115), in the in-beam and out-of-beam directions.

rms SPL threshold (dB re 1 µPa)	In-beam (~0° incidence angle)		Out-of-beam (>20° incidence angle)	
	Best-fit	90th percentile-fit	Best-fit	90th percentile-fit
190	-	2	-	-
180	3	5	-	-
170	10	16	-	-
160	30	45	-	2
150	71	95	2	5
140	130	160	7	17
130	210	240	23	47
120	290	330	58	98
SL term (dB re 1 µPa @ 1 m):	186.7	191.1	154.0	161.5

TABLE 3.52. Side-scan sonar (EdgeTech 4200-MP Dual Frequency) average in-beam received sound levels of 10 pulses, measured at 42 m range and 7 m receiver depth, and source levels derived by 20log*R* back-propagation with absorption coefficients of 24 dB/km at 120 kHz and 92.1 dB/km at 400 kHz.

	Range (m)	Peak SPL (dB re 1 µPa)	rms SPL (dB re 1 µPa)	SEL (dB re 1 µPa^2·s)
120-kHz pulse				
Mean received level	42	170.9	164.8	137.5
Estimated source level	1	204.2	198.1	170.8
400-kHz pulse				
Mean received level	42	166.3	159.3	131.7
Estimated source level	1	202.5	195.5	167.9

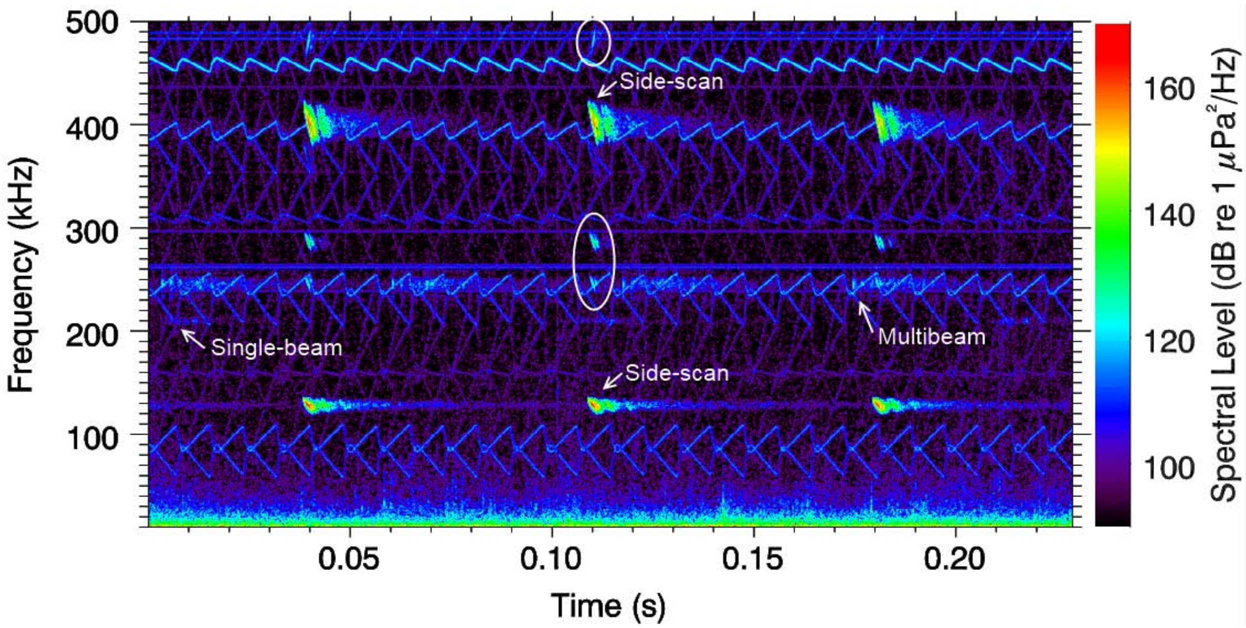

FIGURE 3.116. Spectrogram of three side-scan sonar pulses (EdgeTech 4200-MP Dual Frequency) measured at 42 m range and 7 m receiver depth. Unexpected frequency components of the side-scan sonar are circled. 1024-pt FFT, 1 MHz sample-rate, Hanning window, 128 pt stepsize. The saw-tooth patterns are inducted electrical noise.

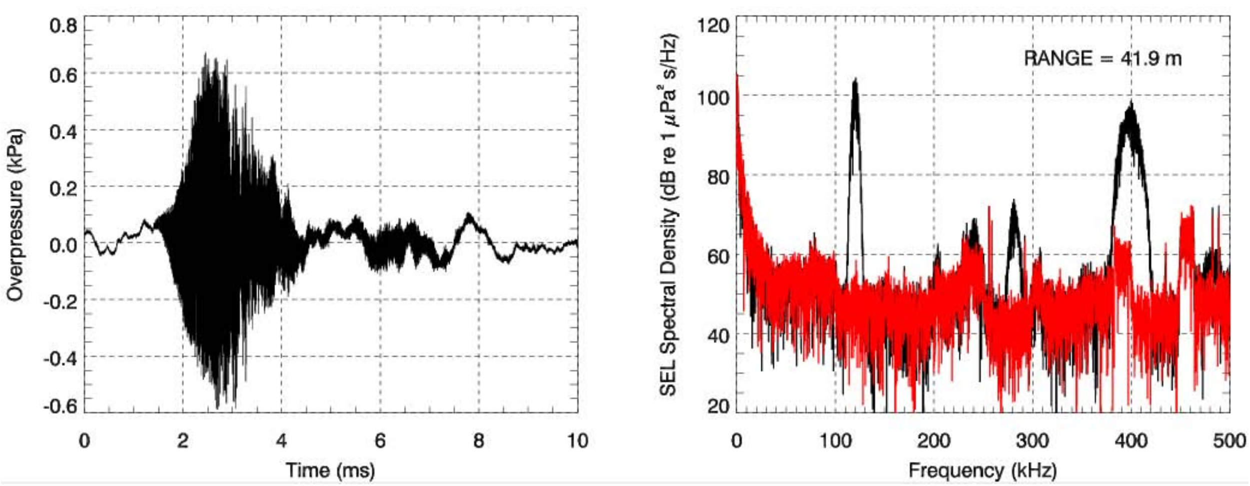

FIGURE 3.117. Side-scan sonar (EdgeTech 4200-MP Dual Frequency) in-beam waveform (left) and SEL spectral density over 10 ms (right) of one pulse measured at 42 m range and 7 m receiver depth. The corresponding spectral density of background noise from the preceding 10 ms window is shown in red.

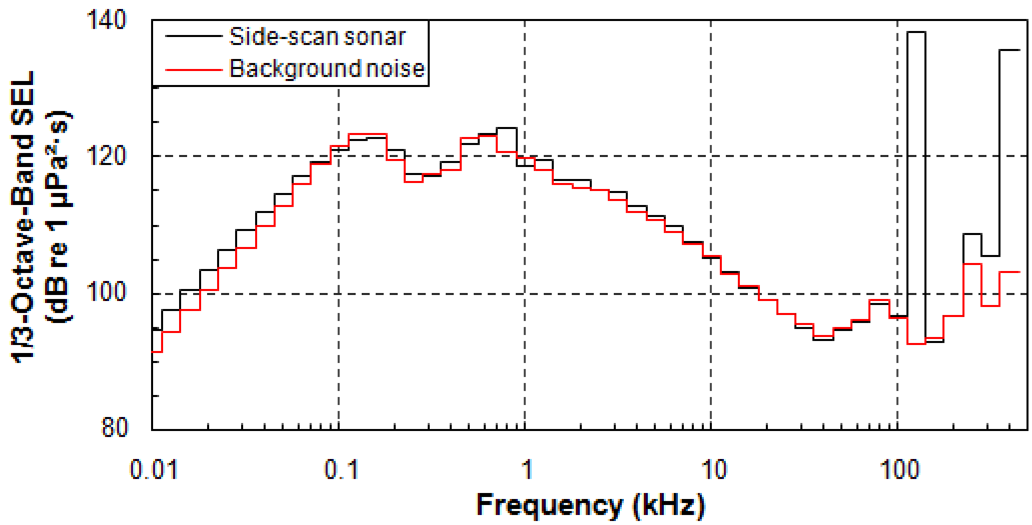

FIGURE 3.118. Side-scan sonar (EdgeTech 4200-MP Dual Frequency) average 1/3-octave band in-beam SEL over 10 ms time windows from 10 pulses measured at 42 m range and 7 m receiver depth. The corresponding average band levels of background noise from the preceding 10 ms windows are shown in red.

Discussion

Survey Vessels

Vessel noise from both the *Ocean Pioneer* and *Mt. Mitchell* varied between the forward and aft directions, with aft sound levels slightly higher than those in the forward directions. Distances to sound level thresholds based on the 90th percentile fits from each vessel transit measurement are summarized below in Table 3.53. Sound levels from the *Ocean Pioneer* operating in Dynamic Positioning (DP) mode are given in Table 3.23. The levels during DP are several decibels higher than those during transits.

TABLE 3.53. Distances to sound level thresholds for the *R/V Ocean Pioneer* and *R/V Mt. Mitchell* measured Aug 2010 at Burger Prospect (Chukchi Sea) and Camden and Harrison Bays (Beaufort Sea).

SPL threshold (dB re 1 μPa)	*Ocean Pioneer*		*Ocean Pioneer*		*Ocean Pioneer*		*Mt. Mitchell*		*Mt. Mitchell*
	Forward	Aft	Forward	Aft	Forward	Aft	Forward	Aft	Broadside†
190	-	-	-	-	-	-	-	-	<10*
180	-	-	-	-	-	-	<5*	<5*	<10*
160	3*	2*	2*	2*	3*	8*	13	21	41*
120	1300	1600	1100	1900	1900	5400**	1500	3900	1800
Location	Burger		Camden Bay		Harrison Bay		Harrison Bay		Harrison Bay
Speed (kts)	10		3.2		3.4		4		10

* Extrapolated beyond minimum range of measurements.
** Extrapolated beyond maximum range of measurements.
† Results highly speculative due to minimum measurement range of only 1330 m.

The *Mt. Mitchell* transit data from the measurement at 10 kts in Harrison Bay were limited due to ice presence at close ranges and noise from other vessels at longer ranges (Fig. 3.90). This limited the useful data to the range interval 1330 m to 2100 m. However these measurements at least captured crossing of the 120 dB re 1 μPa threshold in the broadside direction at 1800 m. The threshold distances for the approach at 10 kts are larger than those for the approach at 4 kts but smaller than those for the departure at 4 kts. This suggests that the vessel noise for *Mt. Mitchell* may be more strongly characterized by direction (higher sound levels aft of the vessel) than by vessel speed. This is not generally the case for vessel noise.

Airgun Systems

The airgun array used for 2010 shallow hazards surveying in Harrison Bay was identical to that used in Shell's 2009 survey at the Burger and Honeyguide prospects in the Chukchi Sea. Distances to sound level thresholds derived from 2010 and 2009 SSVs of the single mitigation airgun and the airgun array are given in Table 3.54 to allow comparisons between the different measurement sites.

TABLE 3.54. Single mitigation airgun (10 in^3) distances to sound level thresholds from 90th percentile least-squares fit to received levels measured 13 Aug in Harrison Bay, Beaufort Sea (forward and aft endfire directions). Distances measured in 2009 at the Honeyguide and Burger Prospects (Warner et al. 2010) are given for comparison.

rms SPL threshold (dB re 1 µPa)	Harrison Bay, 2010		Honeyguide, 2009	Burger, 2009
	Forward	Aft		
190	3*	2*	23*	8*
180	22*	14*	52*	34*
160	600	420	280	570
120	5000	3900	7900	19,000
SL term (dB re 1 µPa @ 1 m)	195.4	192.4	227.3	204.4
Water depth (m)	15	15	48	41

* Extrapolated beyond minimum slant range of measurements.

While the distances to thresholds above 160 dB re 1 µPa (rms) are fairly similar between sites, large differences are observed between the distances to the 120 dB re 1 µPa (rms) threshold. These differences appear to be related to the ability of some environments to support modal (resonant) sound propagation; when modes are present the longer distance levels are higher. This behavior is discussed in terms of spectrograms below.

Table 3.55 presents the threshold distance measurements from the 2009 and 2010 measurements, and provides the pre-season estimated values that are discussed in the IHA. While the pre-season estimate for 160 dB re 1 µPa (rms) threshold distance underestimated the measured value by 28%, the estimate exceeded the 120 dB re 1 µPa (rms) distance by 94%.

TABLE 3.55. Airgun array (40 in^3) distances to sound level thresholds of the from 90th percentile least-squares fit to received levels measured 13 Aug in Harrison Bay, Beaufort Sea (forward and aft endfire directions). Distances measured in 2009 at the Honeyguide and Burger Prospects (Warner et al. 2010) and the distance estimates stated in IHA condition 6(b)(ii) are provided for comparison.

rms SPL threshold (dB re 1 µPa)	Harrison Bay 2010		Honeyguide 2009	Burger 2009	Estimate in 2010 IHA
	Forward	Aft			
190	9*	36	41*	39*	35
180	100	110	99*	150*	125
160	1700	740	600	1800	1220
120	7700	6400	22,000**	31,000**	14,900
SL term (dB re 1 µPa @ 1 m)	198.1	221.4	231.3	218.0	
Water depth (m)	15	15	48	41	

* Extrapolated beyond minimum slant range of measurements.
** Extrapolated beyond maximum range of measurements.

Fig. 3.119 shows a spectrogram of one pulse from the 40 in^3 airgun measured at 10 km range during SSV track 8. The spectrogram indicates a different spectral structure than was observed in the

2009 measurement near the Burger prospect at the same range (Fig. 50 in Warner et. al 2010). The spectrogram in Fig. 3.119 shows that normal mode propagation is not supported at the 2010 Harrison Bay measurement location. The shallow water depth (15 m) is likely not deep enough to support modal sound propagation at low frequencies, and we attribute the absence of energy below 300 Hz in the measurement at 10 km range to this.

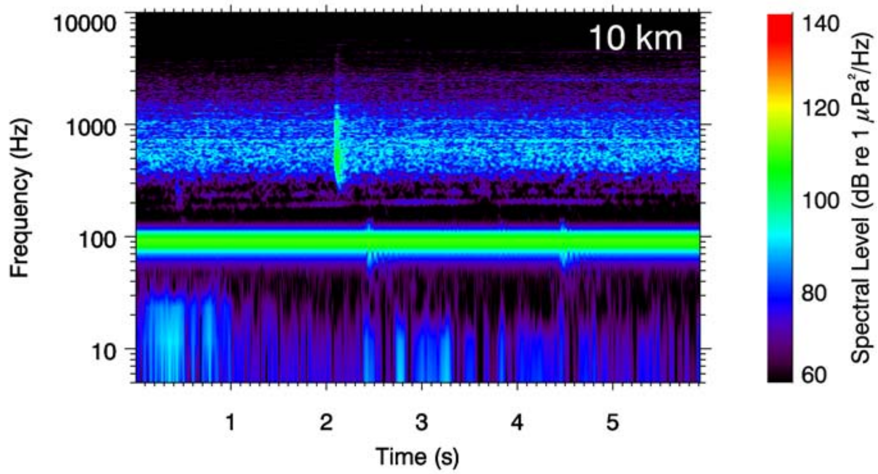

Figure 3.119. Spectrogram of one 40 in^3 airgun array pulse measured at 10 km range in Harrison Bay. 4096-pt FFT, 48 kHz sample-rate, Hanning window, 512-pt step size. The 90 Hz tone in the background is self-noise from the OBH recorder hard disk.

Fig. 3.120 and Fig. 3.121 provide summaries of measurements performed for Shell since 2007 of the 90th percentile distances to several threshold levels for single 10 in^3 airguns and 4×10 in^3 airgun arrays.

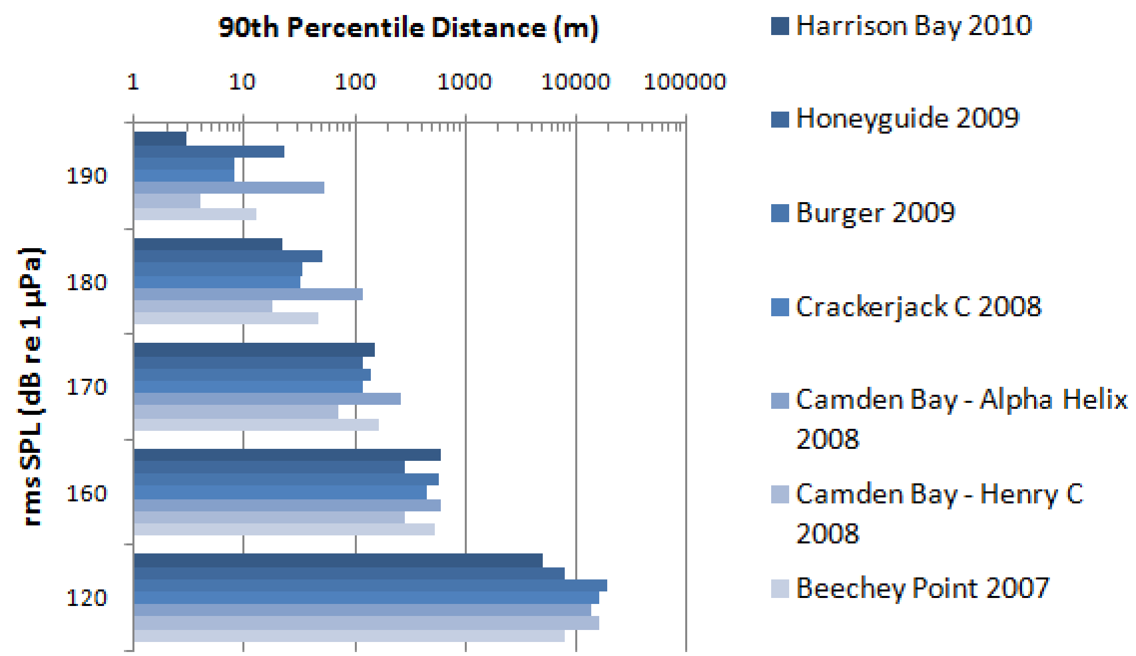

FIGURE 3.120. Distances to sound level thresholds from SSV measurements of single 10 in^3 airguns. Distances are from the 90th percentile fits to SPL versus range data. Harrison Bay 2010 distances are the largest distances between the forward and aft directions.

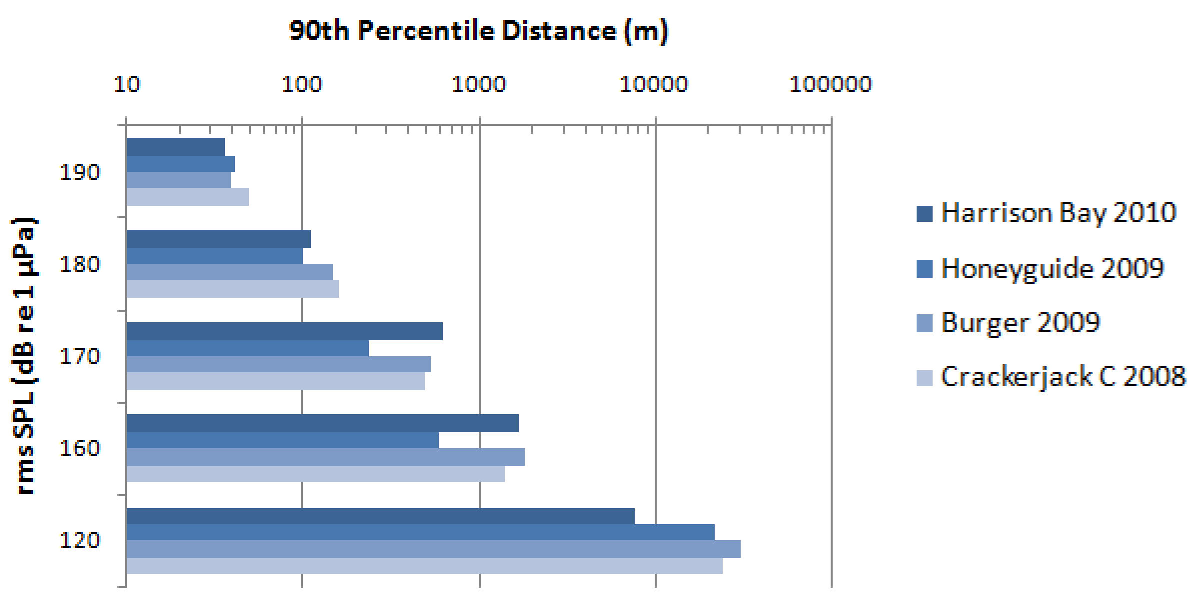

FIGURE 3.121. Distances to sound level thresholds from SSV measurements of 4×10 in^3 airgun arrays. Distances are from the 90th percentile fits to SPL versus range data. Harrison Bay 2010 distances are the largest distances between the forward and aft directions.

Vibracore and Mini-CPT

The maximum measured rms SPL from the Vibracore system was 156 dB re 1 µPa, measured at 74 m slant range. Sound levels varied over the duration of the recording, and percentile levels were calculated to quantify this variation. Distances to sound level thresholds were calculated from the 5th percentile levels using the propagation loss function from the *Ocean Pioneer* transit at the same measurement location (Table 3.56).

TABLE 3.56. Distance to sound level thresholds for the Vibracore obtained by scaling the 5th percentile received rms SPL using the propagation loss function from the *Ocean Pioneer* transit (Equation 10).

rms SPL threshold (dB re 1 µPa)	Distance (m)
170	15
160	69
150	320
140	1500
130	7100
120	30,000
SL (dB re 1 µPa @ 1 m):	187.4

Sounds produced by the mini-cone penetrometer were monitored while the *Ocean Pioneer* operated in DP mode. The mini-cone penetrometer could not be detected above the high background noise levels from the *Ocean Pioneer* in DP. There were no significant differences in 1/3-octave band levels during DP with or without the mini-cone penetrometer in operation.

Sonar

All monitored sonar are listed in Table 3.57 with the broadband source levels as given in the IHA and as calculated by back-propagation and from the 90th percentile fits to sound levels as a function of range as discussed for each measurement in this chapter. The fit functions are primarily intended to estimate levels at distance, and source levels derived using that approach are likely inaccurate in the near-field. The back-propagated levels are believed to accurately represent the source level in the measurement direction; however, as discussed in the measurement results, it was not always possible to confirm the main beam of the directional sonar was sampled. No sonar sources were found to exceed the corresponding source levels specified in the IHA. The RESON SeaBat 8101 multibeam sonar had the highest estimated sonar source level at 201.4 dB re 1 µPa at 1 m (rms).

TABLE 3.57. Sonar source levels as specified in the IHA and as derived by back-propagation and 90th percentile least-squares fit to received level as a function of range.

Source	Mounting	Manufacturer, model	Source level (dB re 1 μPa @ 1 m)		
			IHA	Back-prop.	90th perc. fit
Geotechnical Development Program					
Sub-bottom profiler	Towfish	EdgeTech, 3100 SB-216S	184.6	-	162.1–183.7
Multibeam sonar	Pole, port midship	Kongsberg, EM 3002	-	161.6	-
Sub-bottom profiler	On AUV	EdgeTech, 216	184.6	163.1–167.6*	-
Multibeam sonar	On AUV	Kongsberg, EM 2000	-	177.6–182.2	176.7
Side-scan sonar	On AUV	EdgeTech, Dual frequency	-	164.1–174.5	-
Acoustic comm. signal	On AUV		-	-	208.6
Doppler velocity log	On AUV	RD Instruments, WHN 30	-	182.6–187.3	190.7
Shallow Hazards Program					
Sub-bottom profiler	Pole, port midship	GeoAcoustics, GeoPulse	193.8	-	-
Multibeam sonar	Pole, starboard midship	RESON, SeaBat 8101	-	199.9	201.4
Single-beam sonar	Pole, port midship	Odom, Echotrac CVM	180–200	150.5	-
Side-scan sonar	Towfish	EdgeTech 4200-MP, 120 kHz pulse	225	198.1	157.6–187.4
		400 kHz pulse	-	195.1	161.5–191.1

* Out-of-beam source level.

The center frequencies for each sonar as specified by the manufacturer and as determined from measurements, and the frequency ranges over which measured received levels exceeded background levels are listed in Table 3.58. The measured spectra of the acoustic communication signal of the AUV and the GeoPulse sub-bottom profiler showed spectral leakage outside of the specified frequency range. The EdgeTech 4200-MP side-scan sonar had a measured center frequency of 120 kHz which differed from the specified 100 kHz center frequency. The sub-bottom profilers, AUV acoustic communication signal, and the EdgeTech 4200-MP side-scan sonar produced sounds exceeding background levels at frequencies less than 180 kHz.

TABLE 3.58. Specified (by manufacturer) and measured central frequency (f_c) and measured bandwidth (BW) of main pulse and other non-specified frequency components (if observed) of each sonar.

Source	Manufacturer, model	Main lobe frequencies (kHz)			Other frequencies (kHz)	
		Spec. f_c	Meas. f_c	Meas. BW	Meas. f_c	Meas. BW
Geotechnical Development Program						
Sub-bottom profiler	EdgeTech, 3100 SB-216S	3–12	8	3.5–11.5	-	-
Multibeam sonar	Kongsberg, EM 3002	300	300	280–320	-	-
Sub-bottom profiler	EdgeTech, 216	3–7	5	3–7	-	-
Multibeam sonar	Kongsberg, EM 2000	200	200	180–220	300	290–310
					365	355–375
					400	390–410
Side-scan sonar	EdgeTech, Dual frequency	410	410	385–430	-	-
Acoustic comm. signal	Unknown	24–30	22	21–23	21.5	21–22
					22.5	22–23
Doppler velocity log	RD Instruments, WHN 30	300	300	230–380	200	165–225
					400	385–435
Shallow Hazards Program						
Sub-bottom profiler	GeoAcoustics, GeoPulse	3.5	3.5	1.5–20	-	-
Multibeam sonar	RESON, SeaBat 8101	240	240	230–250	480	470–490
Single-beam sonar	Odom, Echotrac CVM	200	205	200–210	-	-
Side-scan sonar	EdgeTech 4200-MP	100	120	115–125	240	235–245
		400	400	385–410	280	275–290
					480	475–490

The RD Instruments WHN 30 Doppler velocity log was not expected to produce high amplitude sounds and it was not included in the original list of equipment to characterize. However our measurements determined that this source produced the highest-amplitude sounds of all sonar sources mounted on the AUV. It produced sound at frequencies between 230 and 380 kHz, overlapping the EdgeTech dual frequency side-scan sonar pulses. It also produced a lower frequency lobe that extended above background down to 165 kHz. The source level terms and distances to threshold levels are repeated from the *Results* section in Table 3.59 below.

TABLE 3.59 RD Instruments WHN 30 Doppler velocity log 300-kHz pulse source level terms and distances to sound level thresholds (1–7 m receiver depth) from back-propagated SL assuming 20log*R* spreading and an absorption loss coefficient of 63.3 dB/km (see Fig. 3.63).

rms SPL threshold (dB re 1 μPa)	Distance (m)
190	-
180	-
170	2
160	6
150	16
140	42
130	93
120	170
SL (dB re 1 μPa @ 1 m):	175.2

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Appendix A. Ocean Bottom Hydrophone Calibration Data

Table A.1 to Table A.10 present calibration results with the system gain values used in data analysis for OBH Deployments 1–5. For OBH Deployment 1, only pre-deployment measurements were used because both OBHs had stopped recording before retrieval. For OBH Deployments 2–4, the averages of pre- and post-deployment gains were used. No calibrations were performed in the field for OBH Deployment 5, so the laboratory calibration was used.

Fig. A.1 shows the RESON TC 4014 hydrophone sensitivity used to compute gains for all high-frequency measurements.

TABLE A.1. Calibration measurement (Burger Lease, 4 Aug, pre-OBH Deployment 1) used in data analysis for OBH S-02.

Atmospheric Pressure Correction Factor:		-0.04 dB
Atmospheric Pressure:		1008.50 hPa
Bandwidth:		50.0 Hz
CHANNEL #1		CHANNEL #2
Calibrator:	GRAS 42AA	Not used
Frequency:	250.0 Hz	
Sensor:	RESON 4032	
Cal_lev:	136.0 dB re 1 μPa	
Cal_start:	310.0 s	
Cal_len:	40.0 s	
Sysgain:	-179.0 dB re 1 FS/μPa	

TABLE A.2. Calibration measurement (Burger Lease, 4 Aug, pre-OBH Deployment 1) used in data analysis for OBH S-03.

Atmospheric Pressure Correction Factor:		-0.04 dB
Atmospheric Pressure:		1008.50 mbars (=hPa)
Bandwidth:		50.0 Hz
CHANNEL #1		CHANNEL #2
Calibrator:	GRAS 42AA	Not used
Frequency:	250.0 Hz	
Sensor:	RESON 4032	
Cal_lev:	136.0 dB re 1 μPa	
Cal_start:	167.0 s	
Cal_len:	40.0 s	
Sysgain:	-181.2 dB re 1 FS/μPa	

TABLE A.3. Calibration measurement (Burger Lease, 6 Sep, pre-OBH Deployment 2) used in data analysis for OBH S-03.

Atmospheric Pressure Correction Factor:			-0.02 dB
Atmospheric Pressure:			1011.00 mbars (=hPa)
Bandwidth:			50.0 Hz
CHANNEL #1		CHANNEL #2	
Calibrator:	GRAS 42AA	Calibrator:	GRAS 42AA
Frequency:	250.0 Hz	Frequency:	250.0 Hz
Sensor:	RESON 4043	Sensor:	RESON 4032
Cal_lev:	145.5 dB re 1 µPa	Cal_lev:	136.0 dB re 1 µPa
Cal_start:	96.0 s	Cal_start:	197.0 s
Cal_len:	30.0 s	Cal_len:	30.0 s
Sysgain:	-214.2 dB re 1 FS/µPa	Sysgain:	-181.7 dB re 1 FS/µPa

TABLE A.4. Calibration measurement (Burger Lease, 7 Sep, post-OBH Deployment 2) used in data analysis for OBH S-03.

Atmospheric Pressure Correction Factor:			-0.10 dB
Atmospheric Pressure:			1002.00 mbars (=hPa)
Bandwidth:			50.0 Hz
CHANNEL #1		CHANNEL #2	
Calibrator:	GRAS 42AA	Calibrator:	GRAS 42AA
Frequency:	250.0 Hz	Frequency:	250.0 Hz
Sensor:	RESON 4043	Sensor:	RESON 4032
Cal_lev:	145.5 dB re 1 µPa	Cal_lev:	136.0 dB re 1 µPa
Cal_start:	1188.0 s	Cal_start:	1368.0 s
Cal_len:	30.0 s	Cal_len:	30.0 s
Sysgain:	-212.1 dB re 1 FS/µPa	Sysgain:	-181.3 dB re 1 FS/µPa

TABLE A.5. Calibration measurement (Camden Bay, 18 Aug, pre-OBH Deployment 3) used in data analysis for OBH S-02.

Atmospheric Pressure Correction Factor:			-0.04 dB
Atmospheric Pressure:			1009.00 mbars (=hPa)
Bandwidth:			50.0 Hz
CHANNEL #1		CHANNEL #2	
Calibrator:	GRAS 42AA	Calibrator:	GRAS 42AA
Frequency:	250.0 Hz	Frequency:	250.0 Hz
Sensor:	RESON 4043	Sensor:	RESON 4032
Cal_lev:	145.5 dB re 1 µPa	Cal_lev:	136.0 dB re 1 µPa
Cal_start:	37.0 s	Cal_start:	172.0 s
Cal_len:	30.0 s	Cal_len:	30.0 s
Sysgain:	-213.2 dB re 1 FS/µPa	Sysgain:	-179.3 dB re 1 FS/µPa

TABLE A.6. Calibration measurement (Camden Bay, 18 Aug, pre-OBH Deployment 3) used in data analysis for OBH S-03.

Atmospheric Pressure Correction Factor:			-0.04 dB
Atmospheric Pressure:			1009.00 mbars (=hPa)
Bandwidth:			25.0 Hz
CHANNEL #1		CHANNEL #2	
Calibrator:	GRAS 42AA	Calibrator:	GRAS 42AA
Frequency:	250.0 Hz	Frequency:	250.0 Hz
Sensor:	RESON 4043	Sensor:	RESON 4032
Cal_lev:	145.5 dB re 1 µPa	Cal_lev:	136.0 dB re 1 µPa
Cal_start:	76.0 s	Cal_start:	189.0 s
Cal_len:	14.0 s	Cal_len:	34.0 s
Sysgain:	-214.5 dB re 1 FS/µPa	Sysgain:	-181.9 dB re 1 FS/µPa

TABLE A.7. Calibration measurement (Camden Bay, 20 Aug, post-OBH Deployment 3) used in data analysis for OBH S-02.

Atmospheric Pressure Correction Factor:			-0.04 dB
Atmospheric Pressure:			1009.00 mbars (=hPa)
Bandwidth:			50.0 Hz
CHANNEL #1		CHANNEL #2	
Calibrator:	GRAS 42AA	Calibrator:	GRAS 42AA
Frequency:	250.0 Hz	Frequency:	250.0 Hz
Sensor:	RESON 4043	Sensor:	RESON 4032
Cal_lev:	145.5 dB re 1 µPa	Cal_lev:	136.0 dB re 1 µPa
Cal_start:	166.0 s	Cal_start:	32.0 s
Cal_len:	30.0 s	Cal_len:	30.0 s
Sysgain:	-214.2 dB re 1 FS/µPa	Sysgain:	-179.2 dB re 1 FS/µPa

TABLE A.8. Calibration measurement (Harrison Bay, 27 Aug, pre-OBH Deployment 4) used in data analysis for OBH S-03.

Atmospheric Pressure Correction Factor:			-0.03 dB
Atmospheric Pressure:			1010.00 mbars (=hPa)
Bandwidth:			50.0 Hz
CHANNEL #1		CHANNEL #2	
Calibrator:	GRAS 42AA	Calibrator:	GRAS 42AA
Frequency:	250.0 Hz	Frequency:	250.0 Hz
Sensor:	RESON 4043	Sensor:	RESON 4032
Cal_lev:	145.5 dB re 1 µPa	Cal_lev:	136.0 dB re 1 µPa
Cal_start:	75.0 s	Cal_start:	191.0 s
Cal_len:	13.0 s	Cal_len:	30.0 s
Sysgain:	-214.0 dB re 1 FS/µPa	Sysgain:	-181.8 dB re 1 FS/µPa

TABLE A.9. Calibration measurement (Harrison Bay, 27 Aug, post-OBH Deployment 4) used in data analysis for OBH S-03.

Atmospheric Pressure Correction Factor:			-0.03 dB
Atmospheric Pressure:			1010.00 mbars (=hPa)
Bandwidth:			50.0 Hz
CHANNEL #1		CHANNEL #2	
Calibrator:	GRAS 42AA	Calibrator:	GRAS 42AA
Frequency:	250.0 Hz	Frequency:	250.0 Hz
Sensor:	RESON 4043	Sensor:	RESON 4032
Cal_lev:	145.5 dB re 1 µPa	Cal_lev:	136.0 dB re 1 µPa
Cal_start:	3300.0 s	Cal_start:	3420.0 s
Cal_len:	30.0 s	Cal_len:	30.0 s
Sysgain:	-212.1 dB re 1 FS/µPa	Sysgain:	-182.5 dB re 1 FS/µPa

TABLE A.10. Calibration measurement (Victoria BC, 7 Jul, laboratory calibration) used in data analysis for OBH 1 in Harrison Bay (OBH Deployment 5).

Atmospheric Pressure Correction Factor:			0.07 dB
Atmospheric Pressure:			1022.00 mbars (=hPa)
Bandwidth:			50.0 Hz
CHANNEL #1		CHANNEL #2	
Calibrator:	GRAS 42AC	Calibrator:	GRAS 42AC
Frequency:	250.0 Hz	Frequency:	250.0 Hz
Sensor:	RESON 4043	Sensor:	RESON 4032
Cal_lev:	165.5 dB re 1 µPa	Cal_lev:	156.0 dB re 1 µPa
Cal_start:	10.0 s	Cal_start:	10.0 s
Cal_len:	40.0 s	Cal_len:	30.0 s
Sysgain:	-213.1 dB re 1 FS/µPa	Sysgain:	dB re 1 FS/µPa

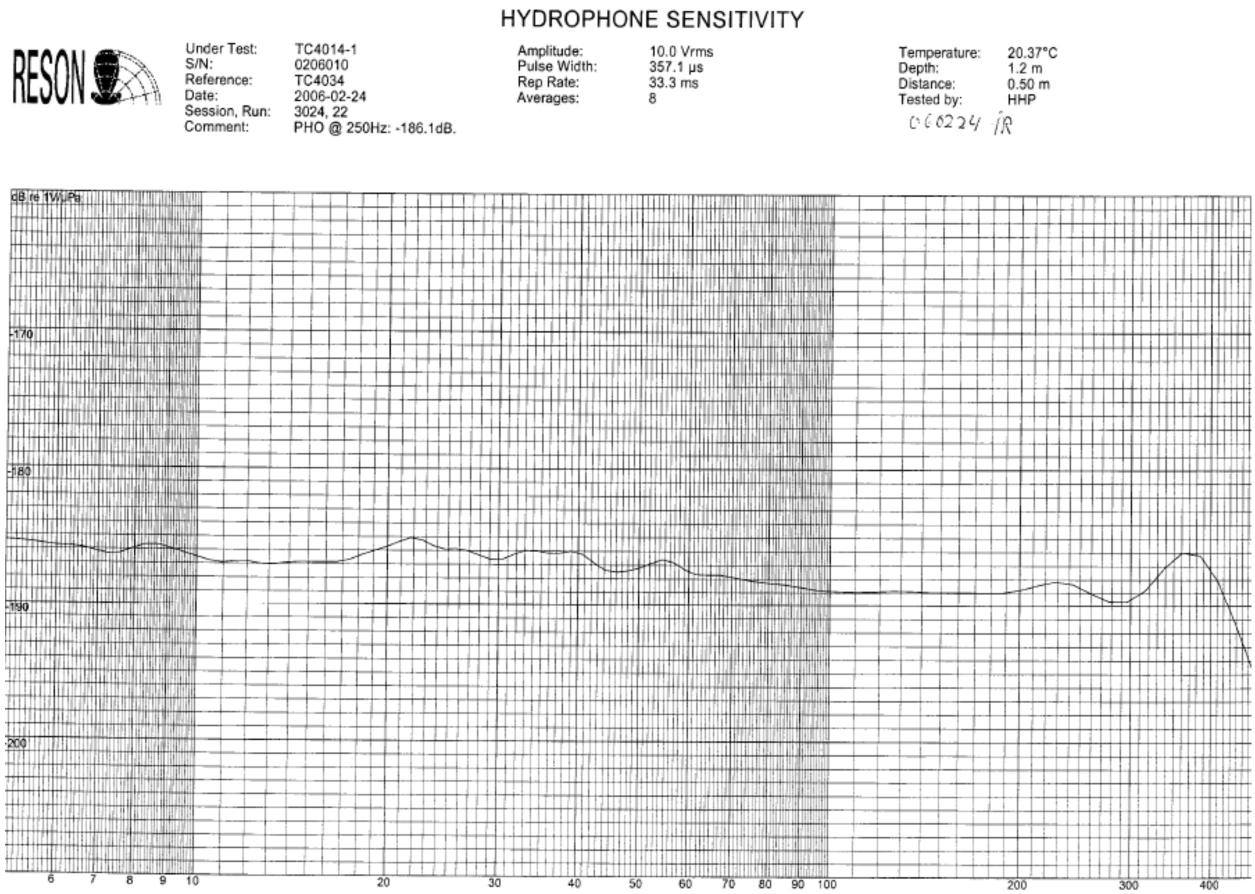

FIGURE A.1. RESON TC 4014 hydrophone sensitivity for high-frequency measurement gain calculation.

4. MONITORING, MITIGATION, AND DATA ANALYSIS METHODS[1]

This chapter describes the marine mammal monitoring and mitigation measures implemented for Shell's marine surveys in the Chukchi and Beaufort Seas during the 2010 open-water season. The required measures were detailed in the IHAs and LoAs (Appendices A and B) issued to Shell by NMFS and USFWS, respectively. The chapter also describes the methods used to categorize and analyze the monitoring data collected by observers and reported in the following chapters.

Monitoring Tasks

The main purposes of the vessel-based monitoring program were to ensure that the provisions of the IHAs and LoAs issued to Shell were satisfied, effects on marine mammals and subsistence use were minimized, and residual effects on animals were documented. Tasks specific to monitoring are listed below (also see Appendices A and B):

- use of dedicated marine mammal observers (MMOs) aboard the seismic source vessel, R/V *Mt. Mitchell*, to visually monitor the occurrence and behavior of marine mammals near the airguns when the airguns are operating and during a sample of the times when they are not;
- use of MMOs aboard the non-seismic survey vessel, R/V *Ocean Pioneer*, and support vessel, M/V *Arctic Seal*, to visually monitor the occurrence and behavior of marine mammals near non-seismic survey activities;
- record (insofar as possible) the effects of the airgun operations and the resulting sounds on marine mammals;
- use the visual monitoring data as a basis for implementing the required mitigation measures;
- estimate the number of marine mammals potentially exposed to airgun sounds at specified levels.

Safety and Potential Disturbance Radii

Under current NMFS guidelines (e.g., NMFS 2000), "safety radii" for marine mammals around airgun arrays are customarily defined as the distances within which received pulsed sound levels are ≥180 dB re 1 μPa (rms) for cetaceans and ≥190 dB re 1 μPa (rms) for pinnipeds. The ≥180 and ≥190 dB (rms) guidelines were also employed by the USFWS for the species under its jurisdiction (Pacific walrus and polar bear, respectively) in the LoA issued to Shell. These safety criteria are based on an assumption that seismic pulses at lower received levels will not injure these animals or impair their hearing abilities, but that higher received levels *might* have some such effects.

Marine mammals exposed to pulsed sound levels ≥160 dB (rms) are assumed by NMFS to be potentially subject to behavioral disturbance. Shell's 2010 IHA required implementation of mitigation measures for large groups (≥12 individuals) of bowhead or gray whales that occurred within an area where sound levels were ≥160 dB (rms) (Appendix A). There has also been concern that received sound levels as low as 120 dB (rms) may have the potential to elicit a behavioral response from bowhead whales during the fall migration in the Beaufort Sea. In 2010, there was a requirement to implement special mitigation measures if four or more bowhead cow/calf pairs were observed by aerial surveyors within the ≥120 dB (rms) radius. Monitoring of the ≥160 and ≥120 dB (rms) zones at specified times and locations is discussed below in the section on *Special Mitigation Measures*.

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[1] By D. S. Ireland, R. Rodrigues, and C. M. Reiser (LGL).

The following sections provide summaries of the measured safety radii and how they were implemented by MMOs during 2010 seismic survey operations in Harrison Bay in the Beaufort Sea. All seismic survey operations during Shell's 2010 marine activities occurred the Beaufort Sea in Harrison Bay. No seismic survey was conducted in the Chukchi Sea.

Pre-sound source verification (SSV) safety radii from Shell's 2010 NMFS IHA and IHA application were implemented for mitigation purposes at the beginning of the 2010 seismic survey until results of the 2010 SSV measurements were available (Table 4.1). Shell conducted a SSV of the *Mt. Mitchell's* airguns in Harrison Bay on 13 and 14 Aug 2010. The measurement results on which MMOs based mitigation decisions during seismic survey operations that were provided in field reports written by JASCO Applied Sciences (JASCO) were later refined during post-season analysis of the acoustic data (Table 4.2). The refined values, which were slightly lower than those in the field reports, were not available for use by the MMOs in the field. However, the refined estimates were used during processing of the monitoring data presented in Chapter 5 and to estimate the numbers of marine mammals exposed to various sound levels.

TABLE 4.1. Radii (in km) for the ≥190, 180, 160, and 120 dB (rms) safety zones that were implemented by MMOs aboard the R/V *Mt. Mitchell* until results of the 2010 SSV from Harrison Bay, Beaufort Sea, were available.

Received Sound Level (dB rms)	Pre-SSV Radii (km)	
	4-airgun array (40 in^3)[a]	1 airgun (10 in^3)[b]
≥190	0.035	0.005
≥180	0.125	0.020
≥160	1.220	0.333
≥120	14.900	8.129

[a] Stipulated in 2010 NMFS IHA, See Appendix A for details

[b] Shell (2010) IHA application

Mitigation Measures as Implemented

Through pre-season meetings with coastal communities and stakeholders, the location and timing of Shell's survey activities, especially in relation to subsistence uses of marine mammals, was determined. These discussions were some of the most significant mitigation measures implemented in 2010. The primary mitigation measures that were implemented during seismic survey operations included ramp up and power down of the airguns (no shut downs were required as a result of a marine mammal sighting). In addition to seismic mitigation measures, general mitigation measures were applied to all survey operations. All daylight non-seismic survey activities were monitored by MMOs to ensure no marine mammals were interacting with vessels or survey gear. Numerous marine mammal sightings, particularly Pacific walrus and bowhead whale sightings, were mitigated through the use of course alteration and reduction of vessel speed. These mitigation measures are standard procedures during marine survey activities and are described in detail in Appendix E. Mitigation also included those measures specifically identified in the IHAs and LoAs (Appendices A and B) as indicated below.

TABLE 4.2. Comparison of the ≥190, 180, 170, 160, 150, 140, 130, and 120 dB (rms) radii (in km) from field reports with refined values based on post-season analysis for sound pulses from the 40–in^3 array and the 10–in^3 mitigation airgun deployed from R/V *Mt. Mitchell* in the Harrison Bay prospect area, Alaskan Beaufort Sea, 2010.

	4-airgun array (40 in^3)		1 airgun (10 in^3)	
Received Sound Level (dB rms)	Preliminary Radii [a]	Final Radii [b]	Preliminary Radii [a]	Final Radii [b]
≥190	0.056	0.036	0.030	0.003
≥180	0.120	0.110	0.086	0.022
≥170	0.590	0.620	0.230	0.150
≥160	1.700	1.700	0.590	0.600
≥150	-	3.000	-	1.400
≥140	-	4.500	-	2.500
≥130	-	6.100	-	3.700
≥120	8.800	7.700	5.700	5.000

[a] Warner and Rideout (2010)

[b] Chorney et al. (2011)

Standard Seismic Mitigation Measures

Standard mitigation measures implemented during the surveys included the following:

1. Safety radii implemented for the seismic activities in the Beaufort Sea were determined based on the results of field measurements of sound sources reported by JASCO (Warner and Rideout 2010; Chapter 3; Table 4.2).
2. Power-down procedures were implemented when a marine mammal was sighted within or approaching the applicable safety radius while the airguns were operating (shut-down procedures were not necessary in 2010 because no marine mammals were observed within or approaching the mitigation gun safety zones).
3. A change in vessel course and/or speed alteration, when practicable, was implemented if a marine mammal was detected outside the safety radius and, based on its position and motion relative to the ship track, was judged likely to enter the safety radius.
4. A ramp-up procedure was implemented whenever operation of the airguns was initiated if >10 min had elapsed since shut down or power down of the full array airguns.
5. In order for seismic operations to start up, the entirety of the largest applicable safety radius to be monitored by MMOs on the vessel must have been visible and clear of marine mammals for at least 30 min.

The specific procedures applied during power downs, shut downs, and ramp ups are described in Appendix E. Briefly, a ***power down*** involved reducing the number of operating airguns from the four-airgun array to a single "mitigation" airgun, when a marine mammal was observed approaching or was first detected already within the full array safety radius. Power down also occurred when the *Mt Mitchell* was between seismic survey lines (e.g., turns) to reduce the amount of sound energy introduced into the water. A ***shut down*** involved suspending operation of all airguns, however, none were required in 2010 as a result of a marine mammal sighting. A ***ramp up*** involved a gradual increase in the number of airguns operating (from no airguns firing) and was usually accomplished by addition of one or two airguns to the operating array once every five minutes. In this report, when a ramp up was initiated while the mitigation airgun had been firing it is referred to as a ***power up***. A ramp up, also called a "cold-start," could not be initiated during times when the full safety radius was not visible to MMOs for 30 minutes if the mitigation gun had not been firing. A power up could be initiated during times when the full safety radii were not visible if the mitigation gun had been firing within 10 minutes prior to the power up.

Special Mitigation Measures as Required by NMFS

In addition to the standard safety radii based on the ≥190 and ≥180 dB (rms) distances for pinnipeds and cetaceans, respectively, NMFS (in the IHA) required Shell to monitor the ≥160 dB (rms) radius for aggregations of 12 or more non-migratory bowhead or gray whales during all seismic activities. Also, Shell was required to monitor the ≥120 dB (rms) radius in the Beaufort Sea with daily aerial surveys (weather permitting) beginning no later than 25 Aug and continuing through five to seven days after all seismic activities had been completed.

Depending on the results of the monitoring of the ≥160 or ≥120 dB (rms) zones, special mitigation measures were to be implemented:

1. Power down or shut down procedures were to be implemented if groups of 12 or more bowhead or gray whales were observed within the≥160 dB (rms) radius while the airguns were in operation.
2. Power down or shut down procedures were to be implemented if four or more bowhead cow/calf pairs were observed during aerial surveys within the ≥120 dB (rms) radius in the Beaufort Sea.

To survey the ≥160 dB (rms) zone for aggregations of whales, MMOs searched the area using "Big Eye" binoculars from the *Mt. Mitchell's* flying bridge in addition to the standard visual monitoring methods conducted from the bridge, which are described in detail in the section below. Based on SSV measurements, the ≥120 dB (rms) radius extended as much as ~8 km (5 mi) from the *Mt. Mitchell*, however, Shell opted to implement an average of their prior 40-in^3 airgun measurements in the Chukchi and Beaufort Seas since 2006 (n = 6) of 25.6 km (15.9 mi) as a conservative measure. Aerial monitoring of the ≥120 dB (rms) zone was required in the Beaufort Sea due to concerns that seismic noise might disturb bowhead whales during migration, particularly cow/calf pairs. In the Beaufort Sea, aerial surveys began on 16 Jul and continued, weather permitting, through 10 Oct. Aerial surveys were attempted daily through 15 Oct, but unfavorable weather precluded the completion of another survey.

In addition to the special seismic mitigation measures above, numerous general mitigation measures were implemented by MMOs aboard all project vessels as required in the Alaskan Chukchi and Beaufort seas. These general mitigation measures included requirements for a vessel to:

1. reduce speed for all sightings of Pacific walruses in water;
2. avoid Pacific walruses and polar bears by 0.8 km (0.5 mi) when practicable;
3. reduce speed to less than 10 kt when within 0.3 km (0.2 mi) of cetaceans;
4. avoid separating individuals within groups of marine mammals.

See Appendices A and B for a comprehensive list of mitigation measures stipulated in the IHAs and LoAs issued to Shell for marine activities in 2010.

Visual Monitoring Methods

Vessel-Based Monitoring—Chukchi and Beaufort Seas

Visual monitoring methods were designed to meet the requirements specified in the IHAs and LoAs (see above and Appendices A and B). The primary purposes of MMOs were as follows: ***(1)*** Conduct monitoring and implement mitigation measures to avoid or minimize exposure of cetaceans and walruses to airgun sounds with received levels ≥180 dB re µPa (rms), or of other pinnipeds and polar bears to≥190 dB (rms). ***(2)*** Conduct monitoring and implement mitigation measures to avoid or minimize exposure of groups of 12 or more bowhead or gray whales to airgun sounds with received levels ≥160 dB (rms). ***(3)*** Conduct monitoring and implement general mitigation measures designed to maximize distance between vessels and marine mammals and to avoid separating individuals within groups of marine mammals. ***(4)*** Document numbers of marine mammals present, any reactions of marine mammals to seismic activities, and whether there was any possible effect on accessibility of marine mammals to subsistence hunters in Alaska. Results of vessel-based monitoring effort are presented in Chapters 5 and 7.

The visual monitoring methods that were implemented during Shell's 2010 marine surveys were similar to those used during various previous seismic cruises conducted under IHAs since 2003. The standard visual observation methods are described below and in Appendix E.

In summary, at least one MMO onboard the *Mt. Mitchell* vessel maintained a visual watch for marine mammals during all daylight and nighttime hours while airguns were in use. Observers focused their search effort forward and to the sides of the vessel but also searched aft of the vessel occasionally. Watches were conducted with the unaided eye, Fujinon 7×50 reticle binoculars, Zeiss 20×60 image stabilized binoculars, and Fujinon 25×150 "Big-Eye" binoculars. MMOs requested seismic operators to power down or shut down the airguns if marine mammals were sighted within or about to enter applicable safety radii.

MMOs onboard the *Ocean Pioneer* and *Arctic Seal* conducted watches similar to those of MMOs onboard the *Mt. Mitchell*, which included monitoring of all daylight survey operations. *Ocean Pioneer* MMOs monitored areas identified for non-seismic marine survey activities *before* the commencement of survey operations and notified operators to delay survey activities if marine mammals were persisting in the area. This was done as a precautionary measure to minimize potential impacts on all marine mammals in the area.

Aerial Surveys—Beaufort Sea

An aerial survey program was conducted in support of the shallow hazard and site clearance survey in Harrison Bay, Beaufort Sea, during 2010. The objectives of the aerial survey were:

- to survey the relevant areas of operations for bowhead cow/calf pairs and report sightings to *Mt. Mitchell* MMOs in real-time to meet requirements in the IHA;
- to collect and report data on the distribution, numbers, direction and speed of travel, and behavior of marine mammals near the seismic operations with special emphasis on migrating bowhead whales;
- to support regulatory reporting related to the estimation of impacts of seismic operations on marine mammals; and

Aerial surveys in Jul and Aug occurred over shallow hazards and site clearance activities and were designed to obtain detailed data (weather permitting) on the occurrence, distribution, and movements of marine mammals, particularly bowhead whales and other cetaceans, in the region surrounding the then current activities as well as in areas of expected future industry activities. Surveys in late Aug to mid-Oct were designed to obtain detailed data centered around the shallow hazard and site clearance survey conducted by the *Mt. Mitchell*, and to monitor the≥120 dB (rms) radius for bowhead whales prior to and during seismic activities. Further details on the aerial survey program and data analysis methods are presented in Chapter 6.

Data Analyses

Vessel-Based Surveys

<u>*Categorization of Data*</u>

Observer effort and marine mammal sightings were divided into several analysis categories related to geographic location, seasonal period, environmental conditions, and seismic activity state. The categories were similar to those used during various other recent seismic studies conducted under IHAs in this region (e.g., Reiser et al. 2010; Ireland et al. 2009; Funk et al. 2008; Ireland et al. 2007a,b; Patterson et al. 2007). These categories are defined briefly below, with a more detailed description provided in Appendix F.

Species Groups – Results are presented separately by species groups including cetaceans, pinnipeds (excluding walrus), Pacific walrus, and polar bear. Cetaceans and pinnipeds were treated separately due to expected differences in behavior and potential reactions to industry activities. Pacific walruses and polar bears were presented separately due to their management by USFWS.

Geographic Boundaries and Seasonal Period – Data were categorized by the geographic region and time period in which they were collected for reporting in Chapters 5 and 7. Only sightings and effort from vessel activities north of Point Hope (68.34 °N) and west of Pt. Barrow (156.45 °W) were included in the Chukchi Sea study areas (Fig. 4.1). The Beaufort Sea study area included data from vessels operating east of Pt. Barrow (156.45 °W) to the Canadian border (141 °W; Fig. 4.1). Vessel activity occurred from late Jul into the second week of Oct, so data collected in Jul and Aug were categorized together and separated from data collected in Sep and Oct.

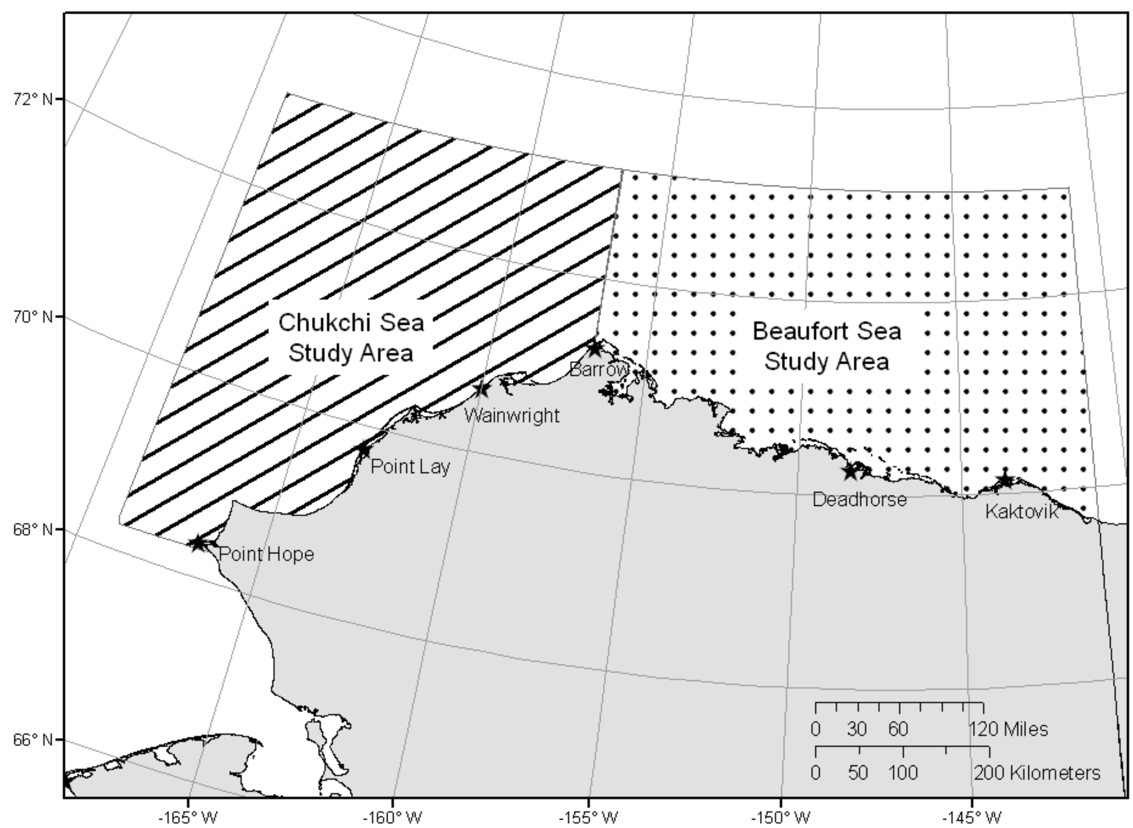

Figure 4.1. The Chukchi Sea and Beaufort Sea study area boundaries used to categorize marine mammal data for analysis and presentation.

Seismic Activity States – Analyses of Beaufort Sea observer effort and marine mammal sightings data were categorized by received sound level (RSL) based on the results from sound source measurements (see Chapter 3). Data were grouped into three received sound level (RSL) bins: (1) ≥160 dB (rms), (2) 159–120 dB (rms), and (3) <120 dB (rms). For the vessel-based results from the Beaufort Sea presented in Chapter 5, the term "seismic" refers to effort and sightings data that were collected in locations where RSL was ≥160 dB (rms). The term "non-seismic" refers to data collected in locations where RSL was <120 dB (rms). "Seismic" data were recorded exclusively from the *Mt. Mitchell* during periods when its airguns were operating because neither of the other two vessels operated inside the *Mt. Mitchell's* ≥160 dB (rms) radius. The 159-120 dB (rms) bin represented intermediate RSLs and accounted for less than 0.2% (<20 km or <12 mi) of observer effort data. This was because the *Ocean Pioneer* and *Arctic Seal* worked almost exclusively outside the Mt. Mitchell's ≥120 dB (rms) radius, and low amounts of survey effort where RSLs were ≥120 dB (rms) precluded meaningful analyses. Therefore, "non-seismic" data included all data from the *Mt. Mitchell* when its airguns were off and all data from the *Ocean Pioneer* and *Arctic Seal* except the insignificant amount of time (~0.2%) they spent transiting in areas where RSLs were between 160 and 120 dB (rms).

<u>*Sighting Rate Calculation and Comparisons*</u>

Sighting rates (sightings/1000 km of observer effort) were presented within the analysis categories of Beaufort Wind Force, number of MMOs on watch, seasonal period, and seismic activity state (for Beaufort Sea vessel-based results, Chapter 5). Sighting rates were presented by species groups including cetaceans, pinnipeds (excluding walruses), Pacific walruses, and polar bears. Where appropriate and sample sizes permitted, comparisons of sightings rates between categories were made using a chi-square (χ^2) test.

Sighting rates have the potential to be biased by a number of different factors. In order to present meaningful and comparable sighting rates, especially for purposes of considering the potential effects of seismic activity on the distribution and behavior of marine mammals, effort and sightings data were categorized by sighting conditions (e.g., environmental conditions), operational conditions, and other vessel proximity. The criteria were intended to exclude data from periods of observation effort when conditions would have made it unlikely or difficult to detect marine mammals that were at the surface. If those data were to be included in analyses, important metrics like sightings rates and densities would be biased downward (Palka 1996; Hammond et al. 1995).

Criteria for Sighting Rate Data – Different definitions were used for pinnipeds (including polar bears) and cetaceans in order to account for assumed differences in their reactions to seismic survey and vessel activities. Therefore, effort and sightings occurring under the following conditions were excluded when calculating vessel-based sighting rates and densities in Chapters 5 and 7:

- periods 3 min to 1 h for pinnipeds and polar bears, or 2 h for cetaceans, after the airguns were turned off (post-seismic period);
- periods when ship speed was <3.7 km/h (2 kt);
- periods when one or more vessels were operating within 5 km (3.1 mi) for cetaceans and 1 km (0.6 mi) for pinnipeds in the forward 180° of the survey vessel;
- periods with seriously impaired visibility including:
    - all nighttime observations;
    - visibility distance <3.5 km (2.2 mi);
    - Beaufort wind force (Bf) >5 (Bf >2 for Minke whales, belugas, and porpoises; See Appendix F for Beaufort wind force definitions);

- >60º of severe glare in the forward 180° of the vessel.

This categorization system was designed primarily to identify potential differences in behavior and distribution of marine mammals during periods with airgun activity versus periods without airgun activity. The rate of recovery toward "normal" behavior and distributions during the post-seismic period is uncertain. Marine mammal responses to seismic sound likely diminish with time after the cessation of seismic activity. The end of the post-seismic period was defined as a time long enough after cessation of airgun activity to ensure that any carry-over effects of exposure to sounds from the airguns would have waned to zero or near-zero. The reasoning behind these categories was explained in MacLean and Koski (2005) and Smultea et al. (2005) and is discussed in Appendix E.

Distribution and Behavior

Marine mammal behavior is difficult to observe because individuals and/or groups are often at the surface only briefly, and may avoid the vessel. This results in difficulties in re-sighting those animals, and in determining whether two sightings some minutes apart are repeat sightings of the same individual(s). Limited behavioral data were collected during this project because marine mammals were often observed at distances too far from the vessel to determine behavior, and they were typically not tracked for long distances or durations while the vessels were underway.

Data collected during visual observations provided some information about behavioral responses of marine mammals to vessels and/or marine survey activities:

- bearings and distances of initial sightings to marine mammals from the MMO observation station;
- observed behavior of animals at the time of the initial sighting;
- animal movements relative to vessel movements; and
- reaction of animals in response to the vessel or seismic sounds (Beaufort Sea, Chapter 5).

Closest Point of Approach – The closest point of approach (CPA) of each sighting to the observer position or airgun array was calculated in a GIS using the closest sighting record to the MMO position on the vessel and then triangulating to the airgun array. T he mean CPA to the observer (for cetaceans, Pacific walruses, and polar bears) or airgun array (for seal sightings in the Beaufort Sea) was calculated. Standard deviation and range of CPA distances (m) were also calculated. For seal sightings in the Beaufort Sea, mean CPAs to the airguns were calculated separately for seismic versus non-seismic sightings and compared.

Similar to sighting rate calculations, the calculation of mean CPA distances and subsequent comparisons during different seismic states could be biased by including data from observation periods of poor visibility or when animals may have been affected by something other than seismic sounds. Therefore, only sightings that met the criteria for inclusion in the sighting rate calculations were used in the calculation of mean CPA distances.

Movement – Animal movements relative to the vessel were recorded for each sighting. Movement patterns were grouped into five categories: swim (move) away, swim (move) towards, neutral (e.g. parallel), none, or unknown.

Initial Behavior – For each sighting an initial behavior was recorded by the MMO. Animal behavior codes included: blow, dive, log, look, mill, rest, surface-active, sink, sink, swim, thrash, bow ride, porpoise, and unknown.

Reaction Behavior – Animal reactions in response to the vessel or survey activities were recorded for each sighting. Reaction behavior codes included: change in direction, increase in speed, look, splash, rush from ice into water, and no reaction.

There were no vessel-based cetacean, Pacific walrus, or polar bear sightings during seismic periods during Shell's 2010 marine surveys in the Beaufort Sea. The proportions of observed movement relative to the vessel, observed initial behavior, and reaction behavior categories above were calculated and compared. For seal sightings in the Beaufort Sea, the proportions of different movement, initial behavior, and reaction behavior categories were calculated separately for seismic and non-seismic sightings and compared.

Line Transect Estimation of Densities

Marine mammal densities were calculated separately for the Chukchi and Beaufort Sea study areas (Figs. 4.1). Marine mammal sightings recorded during Jul–Aug and Sep–Oct were used to calculate densities (# / 1000 km^2) of marine mammals during those seasonal periods. In the Beaufort Sea, densities were further broken down into seismic and non-seismic categories based on sightings during those different vessel activity periods. Density calculations were based on line-transect principles (Buckland et al. 2001). Whenever sample sizes allowed, correction factors for animals not detected at greater distances from the vessels, $f(0)$, were calculated based on data collected from project vessels in the Chukchi and Beaufort seas during 2010 operations. When sufficient sample sizes from 2010 were not available, $f(0)$ correction factors from similar studies in the Chukchi and Beaufort Seas were substituted. Correction factors for animals near the vessel but underwater and therefore unavailable for detection by observers, $g(0)$, were taken from related studies as summarized by Koski et al. (1998) and Barlow (1999). This was necessary because of the inability to assess trackline sighting probability, $g(0)$, during a project of this type. Further details on the line transect methodology used during the survey are provided in Appendix E.

Densities estimated from non-seismic observations in the Beaufort Sea were used (see below) to estimate the numbers of animals that presumably would have been present in the absence of seismic activities in the Beaufort Sea. Densities estimated from non-seismic periods have been used to estimate the numbers of animals present near the seismic operation in the Beaufort Sea and exposed to various sound levels. The difference between the two estimates could be taken as an estimate of the number of animals that moved in response to the operating seismic vessel, or that changed their behavior sufficiently to affect their detectability by visual observers.

Estimating Numbers Potentially Affected

In situations with intermittent impulsive sounds like seismic pulses, NMFS and USFWS assume that "take by harassment" (Level B harassment) may occur if marine mammals are exposed to received levels of sounds exceeding 160 dB re 1 μPa (rms; NMFS 2005, 2006; USFWS 2008). When calculating the number of mammals potentially affected, we used the appropriate measured ≥160 dB (rms) distance shown in Table 4.1.

Two methods were used to estimate the number of pinnipeds and cetaceans exposed to airgun sound levels that may have caused disturbance or other effects. The methods were:

(A) minimum estimates based on direct observations during seismic activities; and

(B) estimates based on pinniped and cetacean densities calculated from data collected during this study multiplied by the area of water ensonified to seismic sounds ≥160 dB (rms).

As noted in the previous section, separate density estimates were calculated from data collected during seismic and non-seismic periods or locations. The use of non-seismic densities in method ***(B)*** provides an estimate of the number of animals that presumably would have been present in the absence of seismic activities. The use of seismic densities in method ***(B)*** provides an estimate of the number of animals that were likely present in the area ensonified to sound levels ≥160 dB (rms). In cases where seismic densities were lower than non-seismic densities, the difference between the two estimates could be taken as an estimate of the number of animals that moved in response to the operating seismic vessel, or that changed their behavior sufficiently to affect their detectability by visual observers. In cases where seismic densities are greater than non-seismic densities, it suggests that individuals of that species did not move in response to the operating seismic vessel, or that they altered their behavior in such a way that made them more detectable by visual observers. The actual number of individuals exposed to, and potentially affected by, seismic survey sounds was likely between the minimum and maximum estimates resulting from methods ***(A)*** and ***(B)***.

Method ***(B)*** above provided an estimate of the number of animals that would have been exposed to airgun sounds at various levels if the seismic activities did not influence the distribution of animals near the activities. However, it is known that some animals are likely to have avoided the area near the seismic vessel while the airguns were firing (see Richardson et al. 1995, 1999; Stone 2003; Gordon et al. 2004; Smultea et al. 2004; Funk et al. 2008). Within the ≥180 dB (rms) radii around the seismic source (i.e., 0.115 km [0.071 mi]), the distribution and behavior of cetaceans may have been altered as a result of the seismic survey. The distribution and behavior of pinnipeds may have been altered within some lesser distance. These effects could occur because of reactions to the active airgun array, or to other sound sources or other vessels working in the area.

Density estimates for each species group were used to estimate the number of animals potentially affected by seismic operations (method ***(B)***). This involved using two approaches to estimate the extent to which marine mammals may have been exposed to given sound levels ≥160, ≥170, ≥180, and ≥190 dB (rms):

1. Estimates of the number of different *individual* marine mammals exposed; and
2. Estimates of the average number of *exposures* each individual may have received.

The ≥160, ≥170, ≥180, and ≥190 dB (rms) distances are summarized in Table 4.2. The following description of the two different methods refers only to the ≥160 dB (rms) sound level, but the same method of calculation was used for ≥170, ≥180 and ≥190 dB (rms) sound levels.

The first method ("individuals") involved multiplying the following three values:

- km of seismic survey;
- width of area assumed to be ensonified to ≥160 dB (rms; 2 × 160 dB [rms] radius), counting the areas ensonified on more than one occasion *only once*; and
- densities of marine mammals estimated from data collected during this survey as described above.

The second approach ("exposures") represents the average number of times a given area of water within the seismic survey area was ensonified to the specified level. The value was calculated as the ratio of the area of water ensonified *including* multiple counts of areas exposed more than once to the area of water ensonified *excluding* multiple counts of areas exposed more than once. If an animal remained in approximately the same location through the duration of the survey activities it would have been exposed an equivalent number of times.

This approach was originally developed to estimate numbers of seals potentially affected by seismic surveys in the Alaskan Beaufort Sea conducted under IHAs (Harris et al. 2001). The method has recently been used in estimating numbers of seals and cetaceans potentially affected by other seismic surveys conducted under IHAs (e.g., Reiser et al. 2010; Ireland et al. 2009; Funk et al. 2008; Ireland et al. 2007a,b; Patterson et al. 2007).

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5. BEAUFORT SEA VESSEL-BASED MARINE MAMMAL MONITORING RESULTS[1]

Monitoring Effort and Marine Mammal Encounter Results

This chapter summarizes the visual observer effort and marine mammal sightings from the *Mt. Mitchell, Ocean Pioneer, and Arctic Seal* during Shell's 2010 marine surveys in the Alaskan Beaufort Sea. The survey period began when the *Mt. Mitchell* entered the Beaufort Sea study area on 2 Aug 2010 (AKDT) and ended when the *Mt. Mitchell* departed the Beaufort Sea study area on 10 Oct 2010. The *Ocean Pioneer* entered and departed the Beaufort Sea study area on 17 Aug and 7 Oct 2010, respectively. The *Arctic Seal* entered and departed the Beaufort Sea study area on 13 Aug and 1 Oct 2010, respectively. During the 2 Aug to 10 Oct survey period, all vessels departed and reentered the Beaufort Sea study area for crew changes and to avoid interfering with the bowhead whale hunt.

Collectively, the three vessels traveled along a total of 16,700 km (10,377 mi) of trackline in the Beaufort Sea study area. The *Ocean Pioneer* and *Arctic Seal* traveled along 5317 km (3304 mi) and 3003 km (1866 mi) of trackline, respectively. The *Mt. Mitchell* traveled along a total of 8350 km (5188 mi) of trackline. Airgun operations occurred along 1453 km (903 mi) of that trackline. The four-airgun array was either ramping up or operating at full array volume (40 in^3) along 1070 km (665 mi) of trackline. The single mitigation gun (10 in^3) operated along 383 km (238 mi) of trackline, including turns for line changes and a single power down for a marine mammal sighting. The *Mt. Mitchell's* airguns did not operate along the remaining 6897 km (4286 mi) of its trackline.

Other Vessels

The *Mt. Mitchell* was not accompanied by a dedicated monitoring vessel, and project vessels did not routinely operate within 5 km (3.1 mi) of other vessels during survey operations. Proximity to other vessels may have influenced the number and behavior of marine mammals sighted from project vessels, however, the extent of this potential influence was unlikely to have been significant. Vessels not participating in the project transited well away from survey activities, and MMOs observed no instances of harassment or disturbance to marine mammals due to the presence of other vessels.

Observer Effort

MMOs on the three vessels were on watch for a total of 11,574 km (7192 mi; 1504 hr) in the Beaufort Sea study area. MMOs aboard the *Mt. Mitchell* remained on watch during all airgun operations (1453 km; 903 mi; 975 hr), including all nighttime use of airguns. A total of 603 km (375 mi; 85 hr) of airgun activity occurred during darkness, during which, MMOs used infrared night vision devices to monitor for marine mammals.

Effort by Seasonal Period

No survey activity occurred in the Beaufort Sea in Jul, but the period was still categorized as Jul–Aug for consistency with other chapters in this report and previous 90-day reports. Data from this early-season period were compared to data from Sep–Oct. More observer effort occurred during the Sep–Oct seasonal period than during Jul–Aug (Fig. 5.1). Effort during periods of darkness was ~3 times greater in Sep–Oct compared to Jul–Aug, and this was because *Mt. Mitchell* MMOs monitored all seismic operations during periods of darkness. Most survey effort was from the *Mt. Mitchell* and *Arctic Seal* in Jul–Aug and from the *Mt. Mitchell* and *Ocean Pioneer* in Sep–Oct.

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[1] By C. M. Reiser, D. M. Savarese, and J. Beland

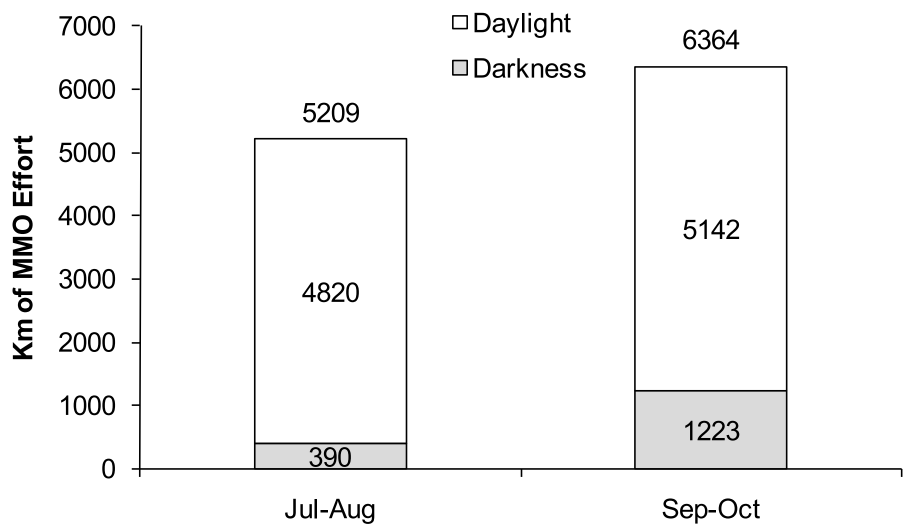

FIGURE 5.1. Marine mammal observer effort (km) by seasonal period and daylight status during Beaufort Sea marine surveys, 2 Aug–10 Oct 2010.

Effort by Beaufort Wind Force

Sea conditions were rougher during MMO watches in Sep–Oct than Jul–Aug during the Beaufort Sea marine surveys in 2010 (Fig. 5.2.) Most observer effort in Jul–Aug (~62%) occurred in sea conditions ≤ Bf 3. In contrast, approximately 68% of observer effort in Sep–Oct occurred in sea conditions ≥Bf 3.

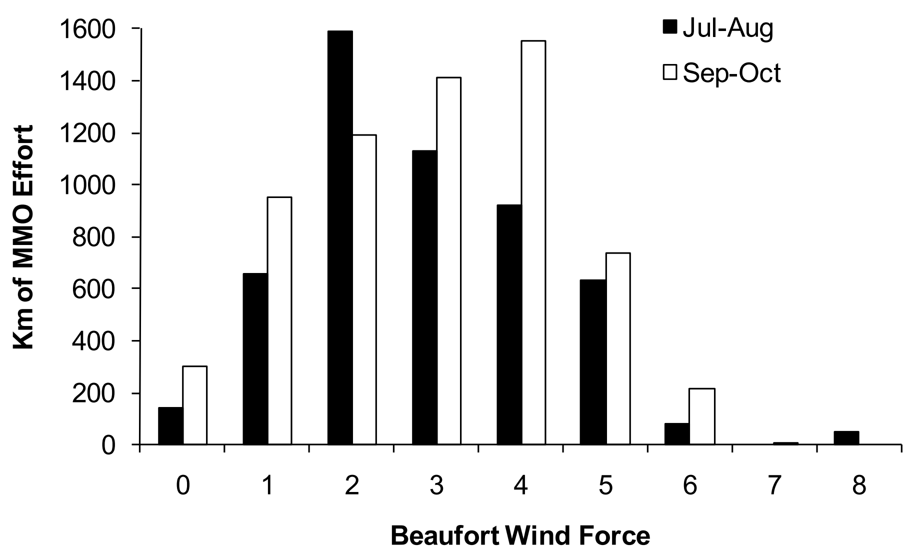

FIGURE 5.2. Marine mammal observer effort (km) by Beaufort wind force and seasonal period during Beaufort Sea marine surveys, 2 Aug–10 Oct 2010.

Effort by Seismic State

Most observer effort occurred during non-seismic periods for both the Jul–Aug and Sep-Nov seasonal periods during Beaufort Sea marine surveys in 2010 (Fig. 5.3). Overall ~13% of observer effort occurred during periods of seismic survey activity. All seismic survey effort (i.e., observer effort when underwater sound levels were estimated to be ≥160 dB [rms]) was recorded from the *Mt. Mitchell*. Neither of the other two vessels operated seismic airguns.

Approximately 21% of observer effort from the *Mt. Mitchell* occurred during periods when the full airgun array or single mitigation gun was active during the 2010 Beaufort Sea marine surveys (Fig. 5.4). Most (~74%) of the seismic survey effort occurred when the full array was operating. Approximately 79% of the overall observer effort on the Mt. Mitchell occurred during periods when no ariguns were operating.

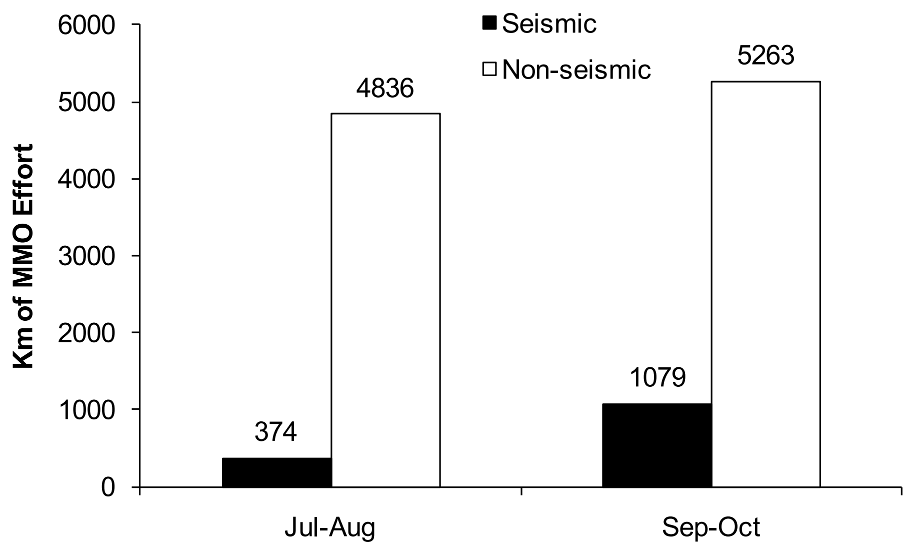

Figure 5.3. Marine mammal observer effort (km) by seismic state and seasonal period for the *Mt. Mitchell*, *Ocean Pioneer*, and *Arctic Seal* during Beaufort Sea marine surveys, 2 Aug–10 Oct 2010. Note that all seismic effort was from the *Mt. Mitchell*, see Fig. 5.4 below for a detailed summary of observer effort by airgun status from the *Mt. Mitchell*.

Effort by number of MMOs

Observer effort with two MMOs on watch was greater than periods with only one MMO on watch during both the Jul–Aug and Sep–Oct seasonal periods (Fig. 5.5). Very little observer effort occurred with three MMOs on watch. The difference in MMO effort by number of MMOs was greater in Jul–Aug compared to Sep–Oct. Overall ~29% of observer effort occurred with one MMO on watch compared to ~70% with two MMOs on watch. All of the two and three MMO watch effort was conducted from the Ocean Pioneer and Mt. Mitchell, which were each staffed with five MMOs. Over 40% of the one MMO watch effort occurred aboard the Arctic Seal, which was staffed with only one MMO.

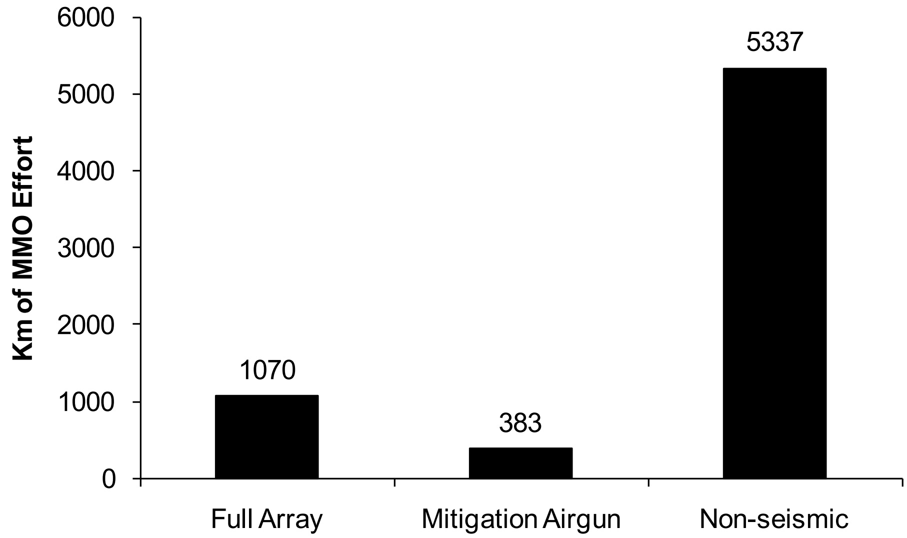

FIGURE 5.4. Marine mammal observer effort (km) from the *Mt. Mitchell* by airgun status during Beaufort Sea marine surveys, 2 Aug–10 Oct 2010. Note that no other Shell vessels operated airguns in the Beaufort Sea during 2010.

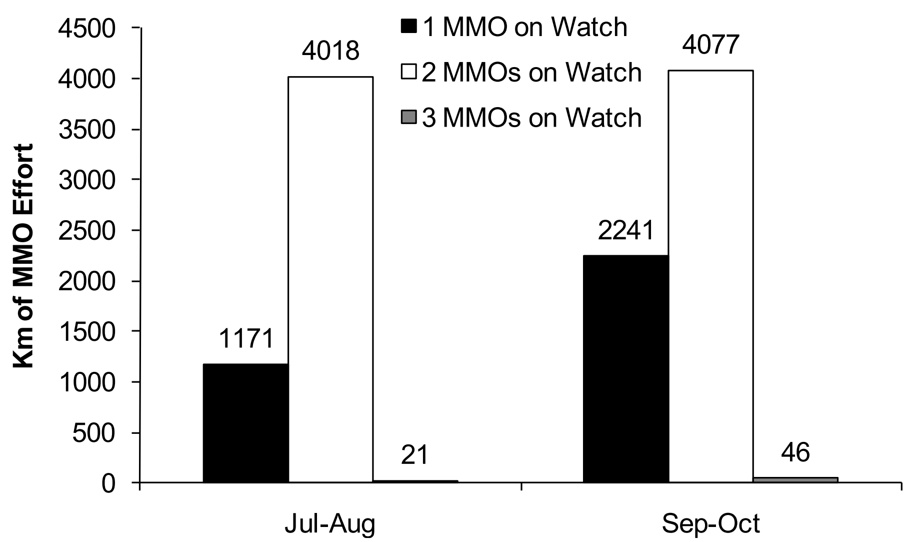

FIGURE 5.5. Marine mammal observer effort (km) by number of MMOs on watch and seasonal period during Beaufort Sea marine surveys, 2 Aug–10 Oct 2010.

Marine Mammal Sightings

MMOs recorded a total of 662 groups of marine mammals (744 individuals) during Beaufort Sea survey operations. See Appendix Table J.5 and Appendix Figures J.1–J.12 for a detailed list of all marine mammal detections and weekly sighting summary maps. Seals were the most commonly observed marine mammals, accounting for 565 sightings (592 individuals). The most commonly identified seal species was ringed seal (*Phoca hispida*), which was recorded on 151 occasions (162 individuals). There were 88 cetacean sightings (134 individuals), and bowhead whale (*Balaena mysticetus*) was the most commonly identified species (49 sightings of 74 individuals). Two sightings (nine individuals) of Pacific walruses (*Odobenus rosmarus*) and seven polar bear (*Ursus maritimus*) sightings (nine individuals) were recorded. No dead or injured marine mammals were observed from any of the three vessels during the 2010 field season. See Appendix J for a detailed summary of each marine mammal sighting during 2010 in the Beaufort Sea study area, including weekly sighting maps.

Cetacean Sightings

More cetacean sightings were recorded in Sep–Oct than Jul–Aug during the Beaufort Sea marine surveys in 2010 (Table 5.1). Bowhead whale was the only cetacean identified to species and comprised ~57% of cetacean sightings. It is likely that many of the unidentified whales were also bowheads. The greater number of bowhead sightings in Sep–Oct compared to Jul–Aug is consistent with the known timing of bowhead fall migration in the Beaufort Sea.

TABLE 5.1. Number of sightings (number of individuals) of cetaceans observed during Beaufort Sea marine surveys, 2 Aug–10 Oct 2010.

Species	Jul - Aug	Sep - Oct	*Total*
Cetaceans			
Bowhead Whale	0	49 (74)	***49 (74)***
Unidentified Mysticete Whale	3 (3)	24 (40)	***27 (43)***
Unidentified Whale	1 (4)	11 (13)	***12 (17)***
Total Cetaceans	***4 (7)***	***84 (127)***	***88 (134)***

Cetacean Sightings by Seismic State

No cetaceans were observed during periods of seismic survey activity in Jul–Aug or Sept-Oct during the 2010 Beaufort Sea marine surveys (Fig. 5.6). All seismic survey activity occurred in shallow areas of Harrison Bay. Most cetacean sightings were recorded in Camden Bay or while transiting to and from Camden Bay in Sep–Oct.

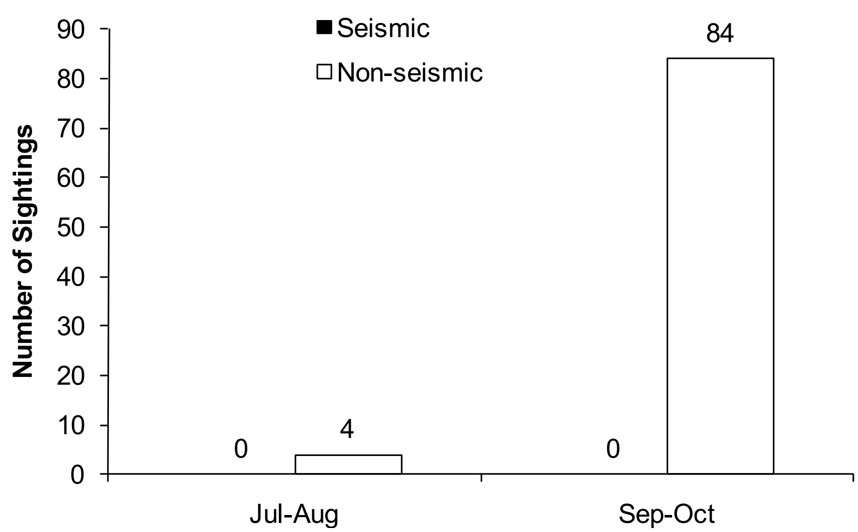

FIGURE 5.6. Number of cetacean sightings by seismic state and seasonal period during Beaufort Sea marine surveys, 2 Aug–10 Oct 2010.

Cetacean Sighting Rates

Cetacean sighting rates were calculated using only the periods of effort that met the criteria for being able to reliably detect cetaceans (See Chapter 4 and Appendix E) and the sightings that occurred during those periods (Appendix Tables J.1 and J.2).

Cetacean Sighting Rates by Seismic State – No cetaceans were recorded during periods of seismic survey activity. The cetacean sighting rate during non-seismic periods was 13.1 sightings per 1000 km (21.1 sightings per 1000 mi) of vessel trackline.

Cetacean Sighting Rates by Beaufort Wind Force – No trend in cetacean sighting rates as a function of Beaufort wind force was apparent during the 2010 Beaufort Sea marine surveys (Fig. 5.7). The highest cetacean sighting rates were recorded when sea conditions were Bf 2 and Bf 5, and the lowest sighting rate was recorded when sea conditions were Bf 1. Cetacean sighting rates were intermediate when sea conditions were Bf 3 and Bf 4.

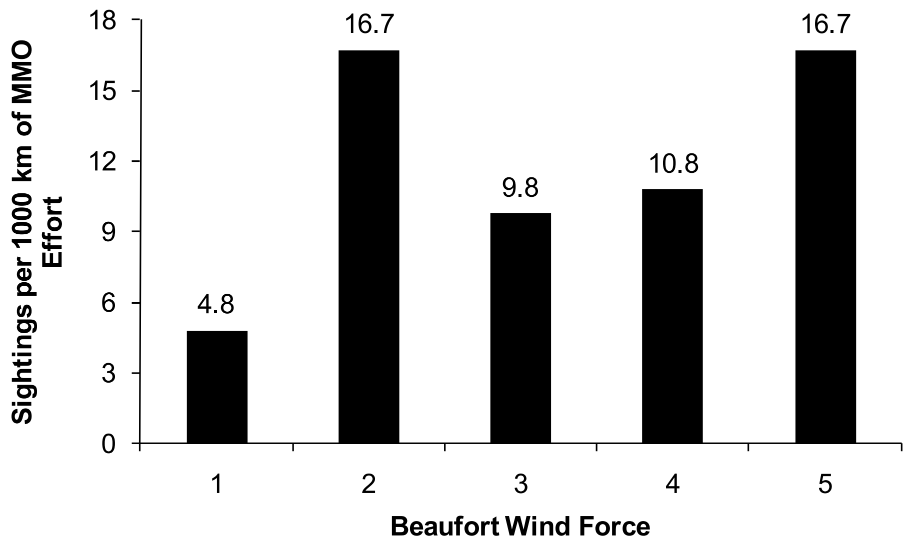

FIGURE 5.7. Cetacean sighting rates by Beaufort wind force during Beaufort Sea marine surveys, 2 Aug–10 Oct 2010. Note that <250 km (155 mi) of observer effort occurred in Bf 0, which precluded meaningful inclusion.

Cetacean Sighting Rates by Seasonal Period and Number of MMOs on Watch – Cetacean sighting rates were greater during Sep–Oct than Jul–Aug regardless of the number of MMOs on watch (Fig. 5.8). Cetacean sighting rates were higher with one MMO than with two MMOs on watch during Jul–Aug. The reverse was true for Sep–Oct, however neither of these results were significant ($\chi^2 = 1.19$, $df = 1$, $p = 0.276$ for Jul–Aug and $\chi^2 = 2.68$, $df = 1$, $p = 0.101$ for Sep–Oct). No significant difference in cetacean sighting rates as a function of number of MMOs on watch was apparent when data from the two seasonal periods were pooled ($\chi^2 = 0.04$, $df = 1$, $p = 0.834$).

Seal Sightings

MMOs recorded 592 seals in 565 groups during the Beaufort Sea marine surveys in 2010 (Table 5.2). Overall, more seals were recorded during Sep–Oct than Jul–Aug although this was not the case for spotted seal (*Phoca largha*) which was recorded more frequently in Jul–Aug. Seals were recorded primarily in water although a few sightings of seals on ice were recorded. Ringed seal was the most abundant seal species and comprised ~58% of the seals identified to species. Bearded (*Erignathus barbatus*) and spotted seals comprised ~30% and 13% of the seals identified to species, respectively. Over half of the seals recorded could not be identified to species.

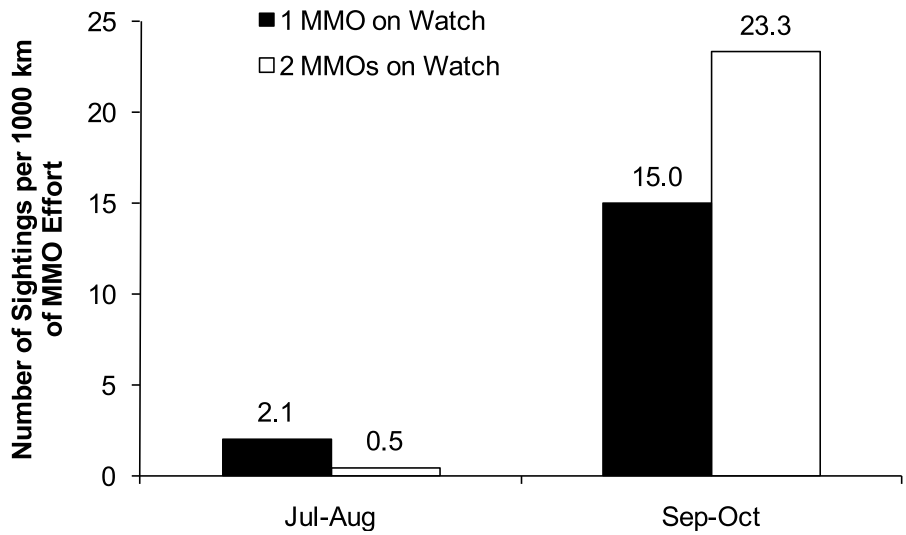

FIGURE 5.8. Cetacean sighting rates by number of MMOs on watch and seasonal period during Beaufort Sea marine surveys, 2 Aug–10 Oct 2010. Note that <250 km (155 mi) of observer effort occurred with 3 MMOs on watch precluding meaningful inclusion.

TABLE 5.2. Number of sightings (number of individuals) of seals observed during Beaufort Sea marine surveys, 2 Aug–10 Oct 2010.

Species and Location	Jul - Aug	Sep - Oct	*Total*
Seals in Water			
Bearded Seal	23 (23)	50 (53)	***73 (76)***
Ringed Seal	72 (76)	78 (85)	***150 (161)***
Spotted Seal	27 (28)	6 (6)	***33 (34)***
Unidentified Seal	115 (116)	165 (174)	***280 (290)***
Unidentified Pinniped	13 (13)	4 (4)	***17 (17)***
Total Seals in Water	***250 (256)***	***303 (322)***	***553 (578)***
Seals on Ice			
Bearded Seal	4 ***(4)***	0	***4 (4)***
Ringed Seal	1 ***(1)***	0	***1 (1)***
Unidentified Seal	5 ***(5)***	1 (1)	***6 (6)***
Unidentified Pinniped	1 ***(3)***	0	***1 (3)***
Total Seals on Ice	***11 (13)***	***1 (1)***	***12 (14)***
Total Seals	***261 (269)***	***304 (323)***	***565 (592)***

Seal Sightings by Seismic State

More seal sightings were recorded during non-seismic than seismic periods in both Jul–Aug and Sep–Oct during the 2010 Beaufort Sea marine surveys (Fig. 5.9), and this is consistent with the amount of watch effort for the two seismic periods (Fig. 5.3). Totals do not include two sightings in Jul–Aug and one sighting in Sep–Oct of seals recorded in locations where underwater sound levels were estimated to be > 120 but <160 dB (rms) during approximately seven km (four mi) of watch effort.

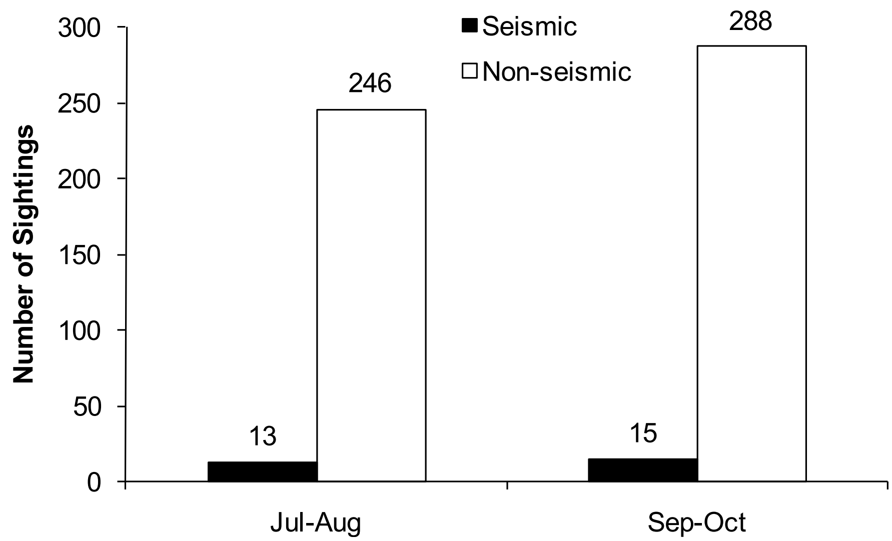

FIGURE 5.9. Number of seal sightings by seismic state and seasonal period during Beaufort Sea marine surveys, 2 Aug–10 Oct 2010.

Seal Sighting Rates

Seal sighting rates were calculated using only the periods of effort that met the criteria for being able to reliably detect seals (See Chapter 4 and Appendix E) and the sightings that occurred during those periods (Appendix Tables J.3 and J.4).

Seal Sighting Rates by Seismic State – No significant difference in seal sighting rates as a function of seismic state was apparent during the Beaufort Sea marine surveys in 2010 (Fig. 5.10; $\chi^2 = 0.45$, $df = 1$, $p = 0.501$).

Seal Sighting Rates by Beaufort Wind Force – Seal sighting rates were higher when sea conditions were calm compared to higher sea conditions (Fig. 5.11). The highest seal sighting rates were recorded when sea conditions were Bf 1 and sighting rates decreased as Bf increased.

Seal Sighting Rates by Seasonal Period and Number of Observers on Watch – Overall, seal sighting rates were significantly higher when two MMOs were on watch compared to periods when only one MMO was on watch (Fig. 5.12; $\chi^2 = 9.31$, $df = 1$, $p = 0.002$). This difference was also significant for the Jul–Aug seasonal period ($\chi^2 = 6.75$, $df = 1$, $p = 0.009$) but only marginally significant for Sep–Oct ($\chi^2 = 3.67$, $df = 1$, $p = 0.055$).

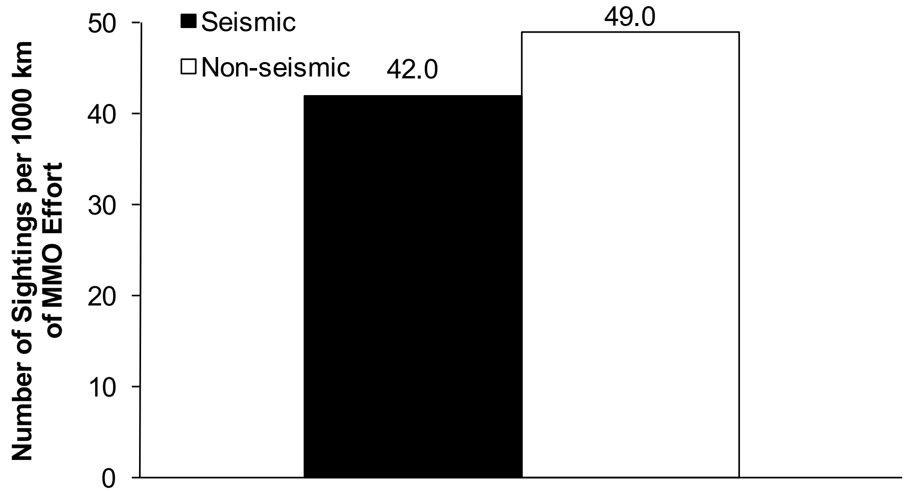

FIGURE 5.10. Seal sighting rates by seismic state during Beaufort Sea marine surveys, 2 Aug–10 Oct 2010.

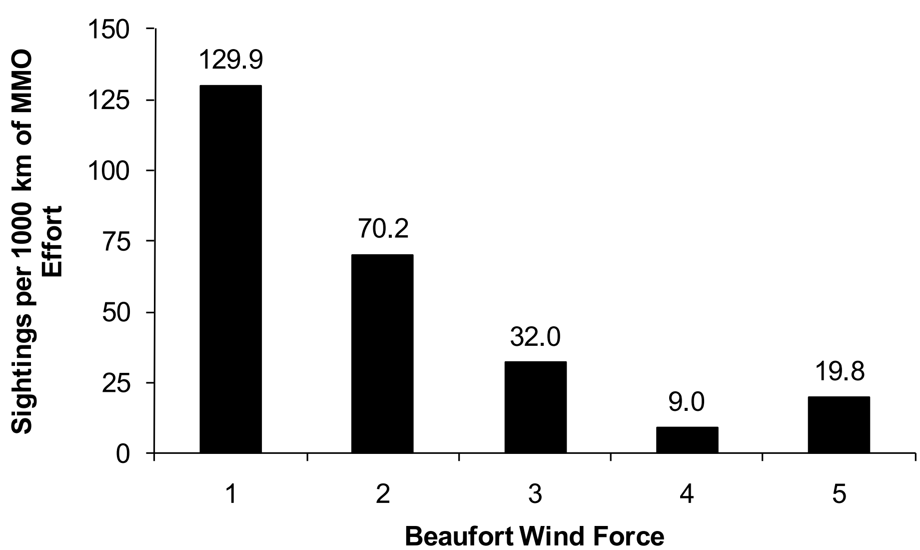

FIGURE 5.11. Seal sighting rates by Beaufort wind force during Beaufort Sea marine surveys, 2 Aug–10 Oct 2010. Note that <250 km (155 mi) of observer occurred in Bf 0 precluding meaningful inclusion.

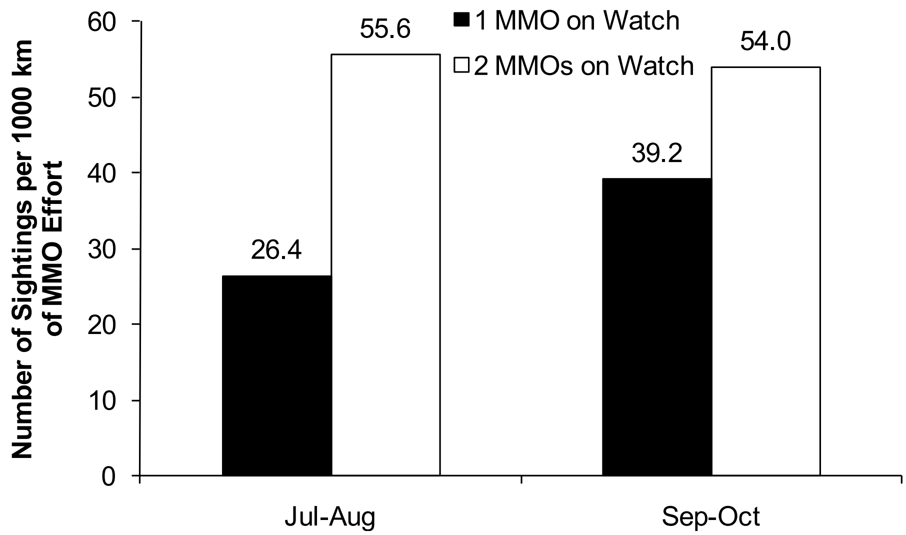

FIGURE 5.12. Seal sighting rates by number of MMOs on watch and seasonal period during Beaufort Sea marine surveys, 2 Aug–10 Oct 2010. Note that <250 km (155 mi) of observer effort took place with 3 MMOs on watch, which precluded meaningful inclusion.

Pacific Walrus Sightings

Two sightings of nine Pacific walruses were recorded during the 2010 Beaufort Sea marine surveys (Table 5.3). Both sightings occurred during periods that did not meet data analysis criteria for detection reliability. The small sample size also precluded meaningful analyses of walrus sighting rates among data categories. Both Pacific walrus sightings were recorded on 23 Aug from the *Mt. Mitchell* when its airguns were not operating, and all of the animals were in water as opposed to on ice.

TABLE 5.3. Number of sightings (number of individuals) of Pacific walruses observed during Beaufort Sea marine surveys, 2 Aug–10 Oct 2010. All walruses were observed in water.

Species	**Jul - Aug**	**Sep - Oct**	***Total***
Pacific Walrus	***2 (9)***	***0***	***2 (9)***

Polar Bear Sightings

Seven sightings (nine individuals) of polar bears were recorded during the 2010 Beaufort Sea marine surveys (Table 5.4). The small number of sightings was insufficient to perform meaningful analyses of sightings data. All polar bear sightings were recorded during non-seismic periods. Three sightings (five individuals) were recorded in Jul–Aug and four sightings (four individuals) were recorded in Sep–Oct. All polar bears were initially observed on ice as opposed to in water.

TABLE 5.4. Number of sightings (number of individuals) of polar bears observed during Beaufort Sea marine surveys, 2 Aug–10 Oct 2010. All polar bears were initially detected on ice.

Species	Jul - Aug	Sep - Oct	*Total*
Polar Bears	***3 (5)***	***4 (4)***	***7 (9)***

Distribution and Behavior of Marine Mammals

Marine mammal behaviors and reactions were difficult to observe because individuals and/or groups of animals typically spent most of their time below the water surface and could not be observed for extended periods. Additionally, the MMOs primary duty was to implement mitigation rather than collect extensive behavioral data. The data collected during visual observations provided limited information about behavioral responses of marine mammals to the 2010 Beaufort Sea marine surveys. The relevant data collected by MMOs included estimated closest observed points of approach (CPA), direction of movement relative to the vessel, and behavior and reaction of animals at the time of the initial detections. We present seismic and non-seismic data and make statistical comparisons of results between the two activity states when possible. None of the cetacean, Pacific walrus, or polar bear sightings, however, were recorded in the survey area where seismic activities occurred, precluding our ability to make statistical comparisons for these species groups on behavior and distribution during different seismic activity states.

Cetaceans

Cetacean Closest Observed Point of Approach

The mean closest point of approach (CPA) of cetaceans was calculated using only sightings that occurred during periods of effort that met the criteria for being able to reliably detect cetaceans (See Chapter 4 and Appendix E). No cetaceans were recorded during periods of seismic survey activity (Table 5.5). Cetacean CPAs during non-seismic periods ranged from ~300 m to 3.5 km from the observer station. The mean cetacean CPA was over 1.3 km from vessels.

TABLE 5.5. Cetacean CPA to MMO station during Beaufort Sea marine surveys, 2 Aug–10 Oct 2010.

Seismic Status	Mean CPA[a] (m)	s.d.	Range (m)	*n*
Seismic	--	--	--	--
Non-seismic	1347	792	300-3594	70
Overall	***1347***	***792***	***300-3594***	***70***

[a] CPA = Marine mammal's closest point of approach to the observer station.

Cetacean Movement

Cetacean movement relative to the vessel was primarily “neutral” or “unknown.” These two categories comprised ~73% of the cetacean movement records (Fig. 5.13). “Neutral” movement indicated that the animal(s) were neither swimming towards nor away from the vessel (e.g., swim parallel). “Swim away” was recorded approximately three times more frequently than “swim toward” the vessel.

Cetacean Initial Behavior

The large distances at which most cetaceans were initially detected from vessels made it difficult to observe specific behaviors compared to pinnipeds. “Blow” and “swim” were the most frequently recorded initial cetacean behaviors comprising ~48 and 35% of the cetacean behavior records, respectively (Fig. 5.14). Other initial behaviors were recorded in much smaller numbers.

Cetacean Reaction Behavior

None of the cetaceans observed from vessels during 2010 in the Beaufort Sea demonstrated a detectable reaction to the vessel. MMOs looked for reactions to the vessel that included “increase speed,” “decrease speed,” “change direction,” “splash,” etc. The large distances at which most cetaceans were observed made any potential reaction to the vessel difficult to distinguish.

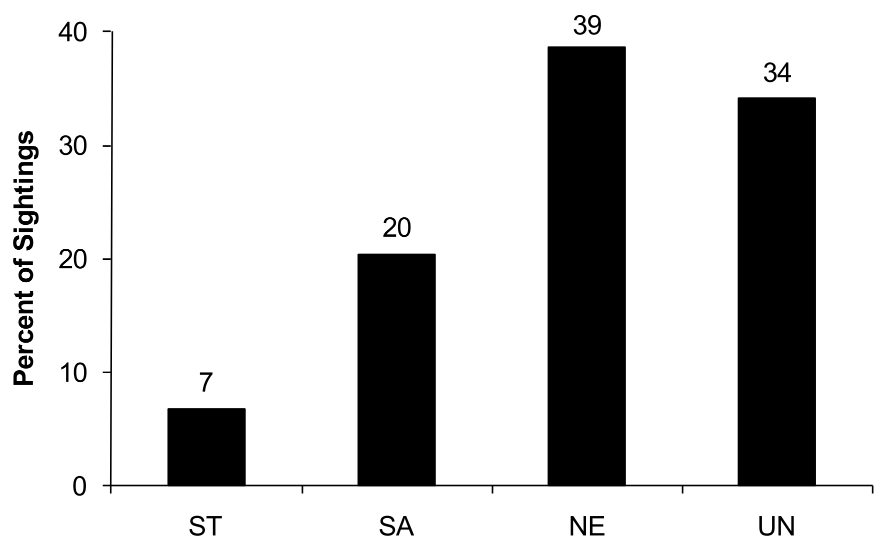

FIGURE 5.13. Cetacean movement with respect to vessels during Beaufort Sea marine surveys, 2 Aug–10 Oct 2010. All sightings were recorded during non-seismic periods, n = 88. Movement codes: ST = Swim Towards, SA = Swim Away, NE = Neutral, UN = Unknown

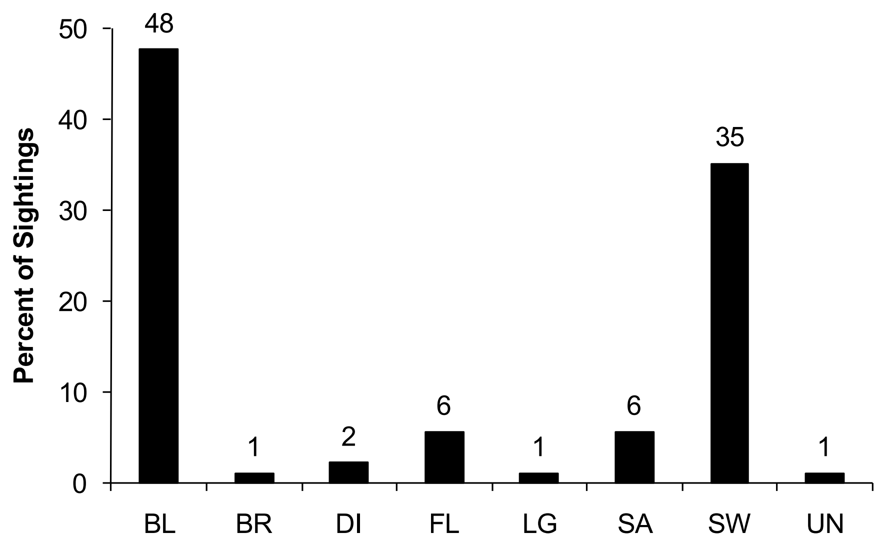

FIGURE 5.14. Cetacean initial behavior during Beaufort Sea marine surveys, 2 Aug–10 Oct 2010. All sightings were recorded during non-seismic periods, *n* = 88. Behavior codes: BL = Blow, BR = Breach, DI = Dive, FL = Fluke, LG = Log, SA = Surface Active, SW = Swim, UN = Unknown

Seals

Seal Closest Observed Point of Approach to Airguns

The mean closest point of approach of seals to the airgun array was calculated using only the sightings that occurred during periods of effort that met the criteria for being able to detect seals (See Chapter 4 and Appendix E). Mean seal CPAs to the airgun array were similar during seismic and non-seismic periods although slightly greater during seismic periods (Table 5.6). The range in CPAs however, was greater during non-seismic periods. The low number of observations during periods of seismic survey activity (21 sightings) was insufficient to perform statistical analysis to compare seal CPAs between seismic and non-seismic periods.

TABLE 5.6. Seal CPA to the airgun array during Beaufort Sea marine surveys, 2 Aug–10 Oct 2010.

Seismic Status	Mean CPA[a] (m)	s.d.	Range (m)	*n*[b]
Seismic	555	299	88-1044	21
Non-seismic	509	415	96-3356	263
Overall	***515***	***403***	***88-3356***	***284***

[a] CPA = Marine mammal's closest point of approach to the airgun array regarless of airgun status

[b] *n* includes only seals in water, seals on ice were excluded from this analysis

Seal Movement

Seal movement patterns relative to vessels were similar during seismic and non-seismic periods (Fig. 5.15). "Neutral" movement (i.e., they swam neither towards nor away from the vessel) was the most frequently recorded movement relative to the vessel during both seismic and non-seismic periods. Smaller numbers of seals "swam away," or "swam towards" the vessel, and the movement pattern could not be determined for about 25% of seal sightings.

Seal Initial Behavior

The pattern in seal behaviors was similar during seismic and non-seismic periods (Fig. 5.16). The most common seal initial behavior was "swim" during both seismic and non-seismic periods. "Look" was the next most frequently recorded seal behavior but was much lower than "swim". Other seal behaviors were recorded less frequently.

Seal Reaction Behavior

The pattern in seal reactions to the vessel recorded by MMOs was similar during seismic and non-seismic periods (Fig. 5.17). Over 65% and 75% of seals demonstrated no detectable reaction to the vessel during seismic and non-seismic periods, respectively. The most commonly observed seal reaction to vessels was to "look" at the vessel, followed by "splash." "Look" at the vessel and "splash" were recorded more frequently during seismic compared to non-seismic periods. Other seal reactions were recorded less frequently.

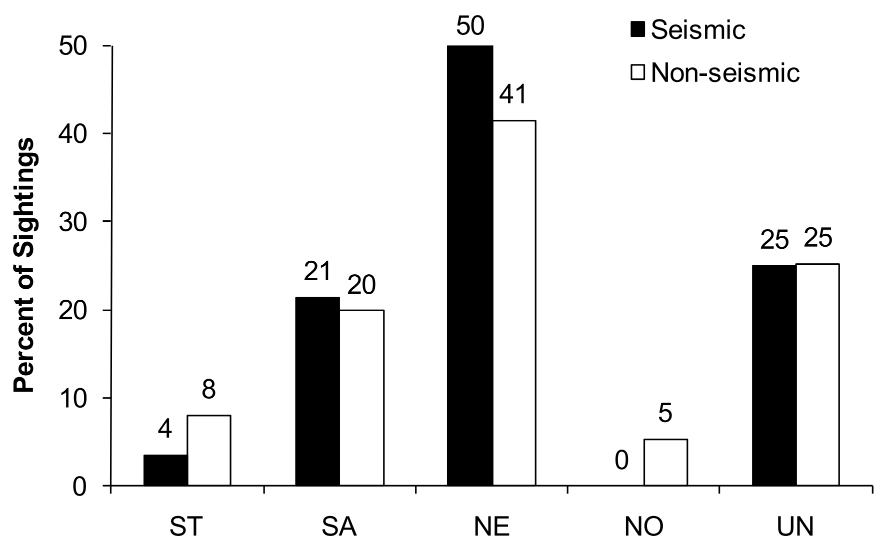

FIGURE 5.15. Seal movement relative to the vessel by seismic state during Beaufort Sea marine surveys, 2 Aug–10 Oct 2010. Only seals in water (Seismic *n* = 28, Non-seismic *n* = 523) were included in this analysis. Movement codes: ST = Swim Towards, SA = Swim Away, NE = Neutral, NO = None, UN = Unknown

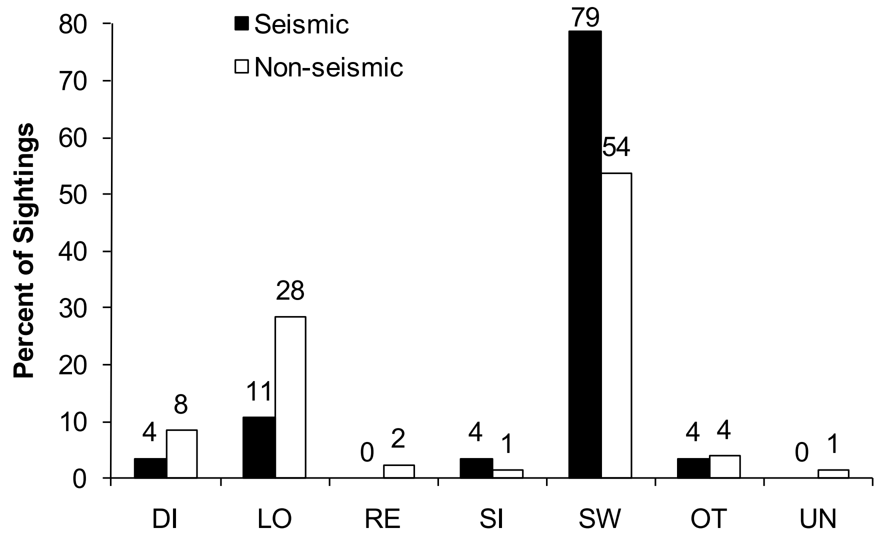

FIGURE 5.16. Seal initial behavior by seismic state during Beaufort Sea marine surveys, 2 Aug–10 Oct 2010. Seals in water and on ice (Seismic *n* = 28, Non-seismic *n* = 534) were included in this analysis. Behavior codes: DI = Dive, LO = Look (but not specifically at vessel), RE = Rest on ice, SW = Swim, OT = Other (Bow Ride, Feed, Log, Porpoise, Surface Active, Thrash), UN = Unknown

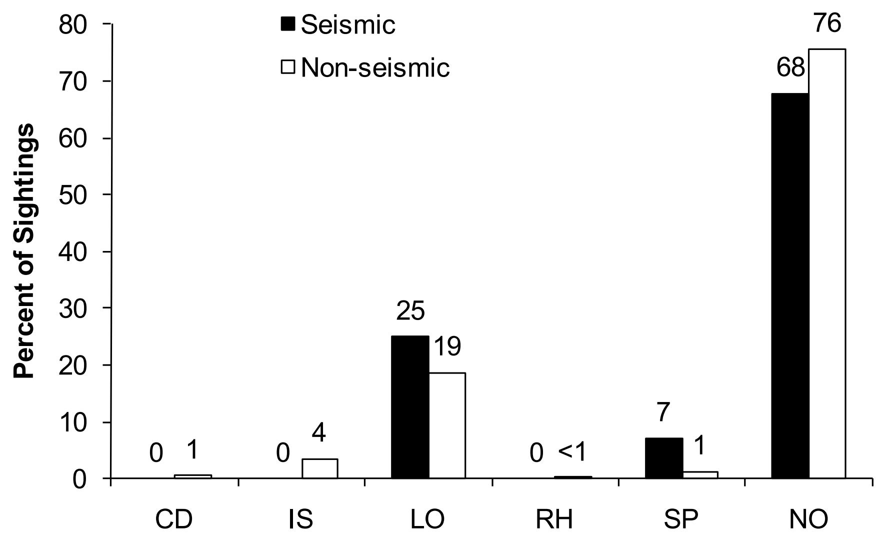

FIGURE 5.17. Seal reaction behavior by seismic state during Beaufort Sea marine surveys, 2 Aug–10 Oct 2010. Seals in water and on ice (Seismic *n* = 28, Non-seismic *n* = 534) were included in this analysis. Reaction behavior codes: CD = Change Direction, IS = Increase Speed, LO = Look at Vessel, RH = Rush from Ice into Water, SP = Splash, NO = No Reaction

Pacific Walruses

CPA, Movement, Initial Behavior, Reaction Behavior

Two sightings of nine Pacific walruses were recorded during the 2010 Beaufort Sea marine surveys. Both sightings were recorded on 23 Aug from the *Mt. Mitchell* when its airguns were not operating. The first group (3 individuals) did not approach the vessel closer than 4 km (2.5 mi) and appeared to be resting in the water. The second group (6 individuals including a single juvenile) approached the vessel to within ~400 m (437 yd) as they swam past. None of the walruses demonstrated a detectable reaction to the vessel.

Polar Bears

Polar Bear CPA

The mean closest point of approach of polar bears to the observer station was calculated using only the sightings that occurred during periods of effort that met the criteria for being able to detect polar bears (See Chapter 4 and Appendix E). No polar bears were observed within one km (0.62 mi) of a survey vessel, and all animals were initially detected on ice. The mean CPA for the five polar sightings that met the analysis criteria was 2066 m (2259 yd; range 1155 to 3340 m [1263 to 3653 yd]), all of which occurred during non-seismic periods.

Polar Bear Movement

For the seven polar bear sightings during the 2010 Beaufort Sea marine surveys, movement relative to the vessel was recorded as “no movement” twice, “swimming towards” the vessel once, and polar bear movement could not be determined for the remaining four sightings.

Polar Bear Initial Behavior

Initial polar bear behaviors were recorded for the seven polar bear sightings during the 2010 Beaufort Sea marine survey. Polar bears were initially observed “resting” on ice on two occasions, “walking” on ice on four occasions, and “looking” (not necessarily at the vessel) once.

Polar Bear Reaction Behavior

No reaction to the vessel was recorded for four of the seven polar bear sightings during the 2010 Beaufort Sea marine surveys. For the other three polar bear sightings, one “rushed” from ice into water and two “looked” at the vessel.

Mitigation Measures Implemented

Shell’s 2010 USFWS LoA for the Beaufort Sea was renewed on 19 May 2010 and its 2010 NMFS IHA was issued on 6 Aug 2010 (Appendices B and A, respectively). The IHA and LoA stipulated numerous general mitigation measures that MMOs implemented throughout the season. These included:

- reducing vessel speed for all Pacific walrus sightings;
- maintaining an 805 m (880 yd or 0.5 mi) marine buffer from all Pacific walruses and polar bears when practicable (this was done for all sightings initially detected at distances greater than 805 m, however, numerous Pacific walruses were initially detected closer than 805 m);
- altering course to avoid separating individuals in groups of marine mammals
- reducing vessel speed to less than 10 kt when a cetacean was within or about to be within 274 m (300 yd) of the vessel;
- reducing vessel speed to below 10 kt during periods of poor visibility (e.g., fog) to reduce the risk of injury to marine mammals;
- avoiding multiple alterations of vessel course and speed when groups of marine mammals were encountered;

- checking areas adjacent to vessel propellers for marine mammals before engaging after idle periods;

In addition to non-seismic mitigation measures stipulated in the IHA and LoA, MMOs concentrated their monitoring efforts around all geophysical survey operations, particularly in the areas directly adjacent to survey gear while it was deployed. MMOs aboard the *Ocean Pioneer* conducted a 30-min watch prior to the deployment of the autonomous underwater vehicle (AUV) to ensure that the area to be surveyed was clear of marine mammals.

The 2010 NMFS IHA stipulated pre-sound source verification (SSV) safety radii for the 40-in^3 airgun array (Table 4.1). The 10-in^3 mitigation gun pre-SSV radii originated from Shell's 2010 IHA application (Shell 2010). Shell conducted a SSV of *Mt. Mitchell* airguns in the Harrison Bay prospect area on 13 and 14 Aug 2010, during which the pre-SSV radii were implemented by MMOs. The preliminary results from this SSV were used to calculate safety radii for all subsequent airgun operations in Harrison Bay during 2010 (Table 4.2).

Two power downs of the airgun array were requested by *Mt. Mitchell* MMOs due to seals that were sighted approaching the ≥190 dB (rms) safety radius of the active array during the Beaufort Sea shallow hazards survey in Harrison Bay (Table 5.7). No power downs or shutdowns of the airguns for cetaceans, Pacific walruses, or polar bears were required during the 2010 survey.

The first power down of airguns was implemented on 1 Oct when a ringed seal was observed approaching the ≥190 dB (rms) safety radius of 56 m (61 yd) for the full array (Table 5.7). The seal was initially detected 162 m (177 yd) from the active airgun array, which was powered down immediately as a precautionary measure because the seal was directly ahead of the vessel trackline. The seal dove and was not seen again. The estimated CPA of the seal to the single mitigation gun was ~160 m (175 yd), which was well outside the ≥190 dB (rms) safety radius of 30 m (33 yd) for the single mitigation gun. The seal showed no detectable reaction to the vessel.

The second power down of airguns was implemented on 10 Oct when a bearded seal was observed approaching the ≥190 dB (rms) safety radius of 56 m (61 yd) for the full array (Table 5.7). The seal was initially detected 88 m (96 yd) from the active airgun array, which was powered down immediately because the seal was directly ahead of the vessel. The seal dove and was not seen again. Its estimated CPA to the single mitigation gun was ~85 m (93 yd), which was well outside the ≥190 dB (rms) safety radius of 30 m (33 yd) for the single mitigation gun. The seal demonstrated a reaction to the vessel by looking at it before diving.

TABLE 5.7. The two power downs for seals observed approaching the *Mt. Mitchell's* ≥190-dB (rms) safety radius in Harrison Bay (56 m; 61 yd) during the Beaufort Sea shallow hazard and site clearance survey, 2 Aug–10 Oct 2010.

Sighting ID	Species	Group Size	Date	Initial Behavior	Reaction to Vessel	Distance (m) to airguns at first detection	CPA (m) to airguns[a]
489	Ringed Seal	1	1-Oct	Swim	None	162	162
499	Bearded Seal	1	10-Oct	Look	Look	88	88

[a] CPA to airguns = Closest Point of Approach to the airgun array

Estimated Number of Marine Mammals Present and Potentially Affected

Meaningful estimates of "take by harassment" were difficult to obtain for several reasons: ***(1)*** The relationship between numbers of marine mammals that are observed and the number actually present is uncertain. ***(2)*** The most appropriate criteria for "take by harassment" are uncertain and presumed to vary among different species, individuals within species, and situations. ***(3)*** The distance to which a received sound level reaches a specific criterion such as 190, 180, 170, or 160 dB re 1 μPa (rms) is variable. The received sound level depends on water depth, sound-source depth, water-mass and bottom conditions, and—for directional sources—aspect (Chapter 3; see also Greene 1997, Greene et al. 1998; Burgess and Greene 1999; Caldwell and Dragoset 2000; Tolstoy et al. 2004a,b). ***(4)*** The sounds received by marine mammals vary depending on their depth in the water, and will be considerably reduced for animals near the surface (Greene and Richardson 1988; Tolstoy et al. 2004a,b) and even further reduced for animals that are on ice.

Two methods were used to estimate the number of marine mammals exposed to seismic sound levels strong enough that they might have caused a disturbance or other potential impacts. The procedures included ***(A)*** minimum estimates based on the direct observations of marine mammals by MMOs, and ***(B)*** estimates based on pinniped and cetacean densities obtained during this study. The actual number of individuals exposed to, and potentially impacted by, strong seismic survey sounds likely was between the minimum and maximum estimates provided in the following sections. Further details about the methods and limitations of these estimates are provided below in the respective sections.

Disturbance and Safety Criteria

Table 4.2 summarizes estimated received sound levels at various distances from the *Mt. Mitchell's* four-airgun array. USFWS required the received sound levels of ≥180 and ≥190 dB re 1 μPa (rms) as mitigation criteria for Pacific walruses and polar bears, respectively, in 2010. The application of the ≥180 dB (rms) criterion for Pacific walruses for the fourth consecutive year was a more conservative approach to walrus mitigation than the use of the ≥190 dB (rms) exclusion zone that was applied in 2006.

Estimates from Direct Observations

The number of animals actually sighted by observers within the various sound threshold distances during seismic activity provided a minimum estimate of the number potentially affected by seismic sounds. Some animals probably moved away before coming within visual range of MMOs, and it was unlikely that MMOs were able to detect all of the marine mammals near the vessel trackline. During daylight, animals are missed if they are below the surface when the ship is nearby. Some other mammals, even if they surface near the vessel, are missed because of limited visibility (e.g., fog), glare, or other factors limiting sightability. Visibility and high sea conditions are often significant limiting factors. Furthermore, marine mammals could not be seen effectively during periods of darkness, which occurred for increasing numbers of hours per day beginning in the second half of Aug. Nighttime observations were not required except prior to and during nighttime power ups and if a power down had been implemented during daytime, however, MMOs aboard the *Mt. Mitchell* stayed on watch throughout the night during all seismic operations in 2010 to monitor survey operations. Infrared night vision devices were used to monitor for marine mammals during periods of darkness.

Animals may also have avoided the area near the *Mt. Mitchell* while the airguns were firing (see Richardson et al. 1995, 1999; Stone 2003; Gordon et al. 2004; Smultea et al. 2004). Within the assumed ≥160–170 dB (rms) radii around the source, and perhaps farther away in the case of the more sensitive species and individuals, the distribution and behavior of pinnipeds and cetaceans may have been altered as a result of the seismic survey. Changes in distribution and behavior could result from reactions to the airguns, or to the *Mt. Mitchell* itself. The extent to which the distribution and behavior of pinnipeds might be affected by the airguns is uncertain, given variable previous results (Harris et al. 2001; Moulton and Lawson 2002; Miller et al. 2005; Reiser et al. 2009). It was not possible to determine if cetaceans beyond the distance at which they were detectable by MMOs exhibited avoidance behavior.

The *Mt. Mitchell* did not have dedicated monitoring vessels given the relatively small size of its marine mammal safety zones. The *Ocean Pioneer* and *Arctic Seal* rarely operated inside the ≥120 dB (rms) radius (<20 km or 12 mi of combined trackline while transiting Harrison Bay). Only one marine mammal was observed from another vessel while it was within the *Mt. Mitchell's* ≥120 dB (rms) radius (see directly below, *Seals Potentially Exposed*)

Cetaceans Potentially Exposed to Sounds ≥180 dB re 1 µPa (rms)

No cetaceans were observed from the *Mt. Mitchell* while the airguns were active during the 2010 Beaufort Sea shallow hazard and site clearance survey. Therefore, zero cetaceans were exposed to received sound levels of ≥180 dB (rms) based on the direct observations of MMOs. It is unlikely that MMOs failed to detect cetaceans within the *Mt. Mitchell's* ≥180 dB (rms) safety zone given the small size of the measured radius (120 m or 131 yd). It is possible, however, that MMOs failed to detect cetaceans inside the ≥180 dB (rms) safety zone during periods of darkness when it is more difficult to detect marine mammals compared to daylight periods.

Seals Potentially Exposed to Sounds ≥190 dB re 1 µPa (rms)

Thirty three individual seals were recorded from the *Mt. Mitchell* while airguns were active during the 2010 Beaufort Sea shallow hazard and site clearance survey. Twenty one seals were sighted while the full airgun array was operating and 12 individuals were observed while the mitigation airgun was firing. None of these seals, however, were observed within or approaching the *Mt. Mitchell's* ≥190 dB (rms) safety zone. Therefore, zero seals were exposed to received sound levels ≥190 dB (rms) based on direct observations by MMOs. It is possible, however, that MMOs failed to detect seals inside the ≥190 dB (rms) safety zone during periods of darkness when it is more difficult to detect marine mammals compared to daylight periods.

There was a single bearded seal observed from the *Arctic Seal* when it was transiting near the *Mt. Mitchell* while the full airgun array was firing, and based on the seal's distance from the array, we estimated that it was exposed to ~130 dB (rms). No other seals were observed by other vessels near the *Mt. Mitchell* while airguns were operating.

Pacific Walruses Potentially Exposed to Sounds ≥180 dB re 1 µPa (rms)

No Pacific walruses were observed from the *Mt. Mitchell* while the airguns were active during the 2010 Beaufort Sea shallow hazard and site clearance survey. Therefore, zero walruses were exposed to received sound levels of ≥180 dB (rms) based on the direct observations of MMOs. It is unlikely that MMOs failed to detect Pacific walruses within the *Mt. Mitchell's* ≥180 dB (rms) safety zone given the small size of the measured radius (120 m or 131 yd). It is possible, however, that MMOs failed to detect walruses inside the ≥180 dB (rms) safety zone during periods of darkness when it is more difficult to detect marine mammals compared to daylight periods.

Polar Bears Potentially Exposed to Sounds ≥190 dB re 1 µPa (rms)

No polar bears were observed from the *Mt. Mitchell* while the airguns were active during the 2010 Beaufort Sea shallow hazard and site clearance survey. Therefore, zero polar bears were exposed to received sound levels of ≥180 dB (rms) based on the direct observations of MMOs. It is unlikely that MMOs failed to detect polar bears within the *Mt. Mitchell's* ≥190 dB (rms) safety zone given the small size of the measured radius (56 m or 61 yd). Furthermore, all polar bears were detected on ice, and the *Mt. Mitchell* could not conduct airgun operations in close proximity to ice..

Estimates Extrapolated from Density

The numbers of marine mammals visually detected by MMOs likely underestimated the actual numbers that were present for reasons described above. To correct for animals that may have been present but not sighted by observers, the sightings recorded during seismic and non-seismic periods along with detectability corrections $f(0)$ and $g(0)$ were used to calculate separate densities of marine mammals present in the project area. These "corrected" densities of marine mammals multiplied by the area of water ensonified (exposed to seismic sounds) were used to estimate the number of *individual* marine mammals exposed to sound levels ≥160, 170, 180, and 190 dB (rms). The average number of *exposures* per individual marine mammal was calculated based on the overlap in ensonified areas around nearby seismic lines considering that an animal remaining in the area would have been exposed repeatedly to the passing seismic source. Marine mammal densities and ensonified areas were calculated independently for Jul–Aug and Sep–Oct to account for seasonal changes in the distribution of marine mammals.

Marine mammal densities were based on data collected from the *Mt. Mitchell, Ocean Pioneer,* and *Arctic Seal* during the 2010 Beaufort Sea shallow hazard and site clearance survey. The density data for the Beaufort Sea survey, including corrections for sightability biases, are summarized in Table 5.8, and the ensonified areas are presented in Table 5.9. The methodology used to estimate the areas exposed to received levels ≥160, 170, 180 and 190 dB (rms) was described in Chapter 4, and in more detail in Appendix E.

The following exposure estimates based on density assume that all mammals present were well below the surface where they were exposed to received sound levels at various distances as predicted in Chapter 3 and summarized in Tables 4.2. Some pinnipeds and cetaceans in the water might remain close to the surface, where sound levels would be reduced by pressure-release effects (Greene and Richardson 1988). Also, some pinnipeds and cetaceans may have moved away from the path of the *Mt. Mitchell* because of an avoidance behavior in response to the approaching vessel and its airguns. The estimated number of exposures based on data collected during non-seismic periods in Tables 5.10–5.13 represented the number of animals that would have been exposed to various received sound levels had they not shown any localized avoidance of the airguns or the ship itself, and therefore likely overestimate actual numbers of animals exposed to those sound levels. Typically, estimates based on densities observed during seismic periods are likely closer to the true numbers of animals that were exposed to the various received sound levels. However, so little observer effort (<300 km or <186 mi for each seasonal period) that met density analysis criteria occurred during seismic periods in 2010 that it was not possible to calculate reliable marine mammal densities from seismic periods.

TABLE 5.8. Estimated densities of marine mammals in the Alaskan Beaufort Sea by seismic state during Beaufort Sea marine surveys, 2 Aug–10 Oct 2010. 95% confidence intervals are in parentheses. Densities are corrected for *f*(0) and *g*(0) biases. Note that less than 500 km (311 mi) of observer effort occurred during seismic periods in both Jul–Aug and Sep–Oct, which precluded calculation of meaningful seismic-period densities.

	No. individuals / 1000 km^2			
	Jul-Aug		Sep-Oct	
Species	Non-seismic	Seismic	Non-seismic	Seismic
Cetaceans				
Bowhead whale	0.000	-	7.635 (2.269 - 25.691)	-
Unidentified mysticete whale	0.176 (0.0140 - 2.222)	-	4.212 (0.890 - 19.930)	-
Unidentified whale	0.706 (0.16349 - 3.047)	-	1.053 (0.232 - 4.776)	-
Total cetacean density	**0.882 (0.221 - 3.529)**	**-**	**12.900 (5.009 - 33.224)**	**-**
Seals				
Bearded seal	24.954 (8.427 - 73.892)	**-**	30.086 (11.579 - 78.171)	**-**
Ringed seal	46.789 (17.182 - 127.411)	**-**	57.765 (23.545 - 141.722)	**-**
Spotted seal	15.596 (5.392 - 45.110)	**-**	3.610 (1.115 - 11.689)	**-**
Unidentified pinniped	4.717 (1.164 - 19.117)	**-**	0.975 (0.269 - 3.538)	**-**
Unidentified seal	62.385 (23.474 - 165.797)	**-**	105.903 (49.704 - 225.646)	**-**
Total seal density	**154.441 (87.697 - 271.983)**	**-**	**198.339 (118.335 - 332.432)**	**-**
Pacific walruses	**6.339 (0.829 - 48.464)[a]**	**-**	**-**	**-**
Polar bears	**0.864 (0.186 - 4.025)[b]**	-	**0.469 (0.097 - 2.268)[b]**	-

"a" indicates density originated from past Beaufort Sea surveys (Funk et al. 2010) with comparable effort and number of sightings

"b" indicates density estimate from polar bears observed on ice, no polar bears were initially detected in the water

"-" indicates reliable density estimate could not be calcualted because <500 km (<311 mi) of effort occurred in the bin

TABLE 5.9. Estimated areas (km^2) ensonified to various sound levels during the Beaufort Sea shallow hazard and site clearance survey, 2 Aug–10 Oct 2010. Maximum area ensonified is shown with overlapping areas counted multiple times; total area ensonified is shown with overlapping areas counted only once.

	Level of ensonification in dB re1µPa (rms)				
Area (km^2)	**120**	**160**	**170**	**180**	**190**
Jul-Aug					
Including Overlap Area	10,966	1310	399	64	20
Excluding Overlap Area	1211	273	145	51	18
Sep-Oct					
Including Overlap Area	36,353	4102	1216	193	60
Excluding Overlap Area	1197	460	326	143	52
2010 Survey Totals					
Including Overlap Area	47,319	5412	1615	257	80
Excluding Overlap Area*	1815	589	384	175	67

* 2010 Survey Totals Exluding Overlap are less than the sum of seasonal period non-overlap areas because many of the same areas were ensonified during both periods.

Cetaceans

Table 5.10 summarizes the estimated numbers of cetaceans that might have been exposed to received sounds at various levels during the 2010 Beaufort Sea shallow hazard and site clearance survey. The density data are shown in Table 5.8, and the ensonified areas are presented in Table 5.9.

(A) ≥160 dB (rms): We estimated that six individual cetaceans would each have been exposed ~five to nine times to airgun pulses with received levels ≥160 dB re 1 µPa (rms) during the survey if all cetaceans showed no avoidance of active airguns or vessels (Table 5.10). Because the only cetacean species identified in the Beaufort Sea in 2010 was bowhead whale (Table 5.1), all of these animals may have been bowhead whales.

(B) ≥170 dB (rms): Some odontocete species may be disturbed only if exposed to received levels of airgun sounds ≥170 dB re 1 µPa (rms). Overall, there would have been ~four individual cetacean exposed to seismic sounds ≥170 dB (rms) approximately three to four times (Table 5.10). However, no odontocetes were observed during 2010 Beaufort Sea surveys.

(C) ≥180 dB (rms): If there was no avoidance of airgun noise by cetaceans, we estimated that there would have been two individual cetaceans exposed one time each to seismic sounds ≥180 dB (rms; Table 5.10). However, most cetaceans probably moved away before being exposed to received levels ≥180 dB (rms). As noted earlier, no cetacean sightings were reported from the *Mt. Mitchell* during seismic operations.

Seals

Table 5.11 summarizes the estimated numbers of seals potentially exposed to various received sound levels during the 2010 Beaufort Sea shallow hazard and site clearance survey. Exposure estimates were based on the ensonified areas (Table 5.9) and non-seismic seal densities observed during the survey (Table 5.8).

TABLE 5.10. Estimated numbers of individual cetaceans exposed to received sound levels ≥160, 170, 180, and 190 dB (rms) and average number of exposures per individual during the Beaufort Sea shallow hazard and site clearance survey, 2 Aug–10 Oct 2010. Estimates were based on "corrected" non-seismic and seismic densities.

Seasonal Period and Exposure level in dB re 1µPa (rms)	Non-seismic Densities		Seismic Densities	
	Individuals	Exposures per Individual	Individuals	Exposures per Individual
Jul-Aug				
≥160	1*	5	-	NA
≥170	1*	3	-	NA
≥180	1*	1	-	NA
≥190	1*	1	-	NA
Sep-Oct				
≥160	6	9	-	NA
≥170	4	4	-	NA
≥180	2	1	-	NA
≥190	1*	1	-	NA
Survey Totals				
≥160	6	5 to 9	-	NA
≥170	4	3 to 4	-	NA
≥180	2	1	-	NA
≥190	1*	1	-	NA

"1*" indicates number of individuals was decimal value between 0 and 1

"-" indicates <500 km (<311 mi) of observer effort within the density bin and no sightings during seismic periods

(A) ≥160 dB (rms): We estimated that ~133 individual seals would have been exposed ~five to nine times each to airgun pulses with received levels ≥160 dB re 1 µPa (rms) during the survey, assuming no avoidance of the ≥160 dB (rms) zone (Table 5.11). Based on the available non-seismic densities and proportion of identified species, approximately 78 of the animals would have been ringed seals, 38 would have been bearded seals, and 17 would have been spotted seals.

(B) ≥170 dB (rms): Some seals may be disturbed only if exposed to received levels ≥170 dB re 1 µPa (rms). Overall, there would have been ~87 individual seals each exposed ~three to four times to seismic sounds ≥170 dB (rms; Table 5.11).

(C) ≥180 dB (rms): We estimated that ~36 individual seals were each exposed once to sounds ≥180 dB (rms) assuming no avoidance of the seismic survey activities (Table 5.11).

(D) ≥190 dB (rms): Based on densities calculated from sighting rates during non-seismic periods, we estimated that there would have been 13 individual seals exposed once each to received levels ≥190 dB (rms) if there was no avoidance of seismic sounds (Table 5.11). This estimate was higher than the number of seals exposed to received levels ≥190 (rms) based on direct observations (n = 0). Some pinnipeds within the ≥190 dB (rms) radius presumably were missed during times when MMOs were on watch. Even during times when MMOs were on watch, some seals at the surface could have been missed due to brief surface times, poor visibility, rough seas, and other factors. Because of this, density-based

estimates of exposures and exposed individuals are higher than those based on direct observation. The actual number of seals exposed to received sound levels ≥190 dB (rms) was probably lower than the estimate calculated from non-seismic densities, but greater than that from direct observations.

TABLE 5.11. Estimated numbers of individual seals exposed to received sound levels ≥160, 170, 180, and 190 dB (rms) and average number of exposures per individual during the Beaufort Sea shallow hazard and site clearance survey, 2 Aug–10 Oct 2010. Estimates were based on "corrected" non-seismic and seismic densities.

Seasonal Period and Exposure level in dB re 1µPa (rms)	Non-seismic Densities		Seismic Densities	
	Individuals	Exposures per Individual	Individuals	Exposures per Individual
Jul-Aug				
≥160	42	5	-	5
≥170	22	3	-	3
≥180	8	1	-	1
≥190	3	1	-	1
Sep-Oct				
≥160	91	9	-	9
≥170	65	4	-	4
≥180	28	1	-	1
≥190	10	1	-	1
Survey Totals				
≥160	133	5 to 9	-	5 to 9
≥170	87	3 to 4	-	3 to 4
≥180	36	1	-	1
≥190	13	1	-	1

"-" indicates <500 km (<311 mi) of observer effort within the density bin and a reliable density could not be calculated

Pacific Walruses

Table 5.12 summarizes the estimated numbers of Pacific walruses potentially exposed to received sounds of various levels during the 2010 Beaufort Sea shallow hazard and site clearance survey. Exposure estimates were based on the ensonified areas (Table 5.9) and a walrus density estimate from past Beaufort Sea surveys (Funk et al. 2010; Table 5.8). It was not possible to calculate density estimates for Pacific walruses using data collected during the 2010 survey because the two sightings occurred during periods that did not meet the criteria for reliable walrus detection (See Chapter 4 and Appendix E). The Funk et al. (2010) Pacific walrus density reported for Sep–Oct in the Beaufort Sea was chosen because the number of sightings and watch effort used to calculate the density estimate were comparable to 2010.

(A) ≥160 dB (rms): We estimated that ~two individual Pacific walruses would have been exposed ~five times each to airgun pulses with received levels ≥160 dB re 1 µPa (rms) during the survey, assuming no avoidance of the ≥160 dB (rms) zone (Table 5.12).

(B) ≥170 dB (rms): Some Pacific walruses may be disturbed only if exposed to received levels ≥170 dB re 1 µPa (rms). Overall, there would have been ~one individual walrus each exposed ~three to four times to seismic sounds ≥170 dB (rms; Table 5.12).

(C) ≥180 dB (rms): We estimated that ~one individual walrus was exposed once to sounds ≥180 dB (rms) assuming no avoidance of the seismic survey activities (Table 5.12).

(D) ≥190 dB (rms): Based on densities reported in Funk et al. (2010) from past Beaufort Sea seismic surveys, we estimated that there would have been ~one individual walrus exposed once to received levels ≥190 dB (rms) if there was no avoidance (Table 5.12).

TABLE 5.12. Estimated numbers of individual Pacific walruses exposed to received sound levels ≥160, 170, 180, and 190 dB (rms) and average number of exposures per individual during the Beaufort Sea shallow hazard and site clearance survey, 2Aug–10 Oct 2010. Estimates were based on “corrected” non-seismic and seismic densities.

Seasonal Period and Exposure level in dB re 1µPa (rms)	Non-seismic Densities		Seismic Densities	
	Individuals	Exposures per Individual	Individuals	Exposures per Individual
Jul-Aug				
≥160	2	5	-	NA
≥170	1*	3	-	NA
≥180	1*	1	-	NA
≥190	1*	1	-	NA
Sep-Oct				
≥160	0	9	-	NA
≥170	0	4	-	NA
≥180	0	1	-	NA
≥190	0	1	-	NA
Survey Totals				
≥160	2	5 to 9	-	NA
≥170	1*	3 to 4	-	NA
≥180	1*	1	-	NA
≥190	1*	1	-	NA

"1*" indicates number of individuals was decimal value between 0 and 1

"-" indicates <500 km (<311 mi) of observer effort within the density bin and no sightings during seismic periods

Polar bears

Table 5.13 summarizes the estimated numbers of polar bears potentially exposed to received sounds of various levels during the 2010 Beaufort Sea shallow hazard and site clearance survey if they had been in the water. All polar bears observed in 2010 were initially detected on ice during non-seismic periods. Exposure estimates were based on the ensonified areas (Table 5.9) and density estimates from animals observed on ice (Table 5.10). During seismic periods, it would have been unlikely that any polar bears on ice would have been exposed to the same received sound level as animals in water at the same distance. Therefore, the polar bear exposure estimates using in-water densities were zero.

(A) ≥160 dB (rms): We estimated that ~one polar bear would have been exposed ~five to nine times each to airgun pulses with received levels ≥160 dB re 1 µPa (rms) during the survey, assuming no avoidance of the ≥160 dB (rms) zone if it had been in the water as opposed to on ice (Table 5.13).

(B) ≥170 dB (rms): Some polar bears may be disturbed only if exposed to received levels ≥170 dB re 1 µPa (rms). Overall, there would have been ~one polar bear exposed ~two to three times to seismic sounds ≥170 dB if it had been in the water (rms; Table 5.13).

(C) ≥180 dB (rms): We estimated that ~one polar bear would have been exposed once to sounds ≥180 dB (rms) assuming no avoidance of the seismic survey activities if it had been in the water (Table 5.13).

(D) ≥190 dB (rms): Based on on-ice polar bear densities, we estimated that there would have been ~one polar bear exposed once to received levels ≥190 dB (rms) if there was no avoidance and if it was not on ice (Table 5.13).

TABLE 5.13. Estimated numbers of individual polar bears exposed to received sound levels ≥160, 170, 180, and 190 dB (rms) and average number of exposures per individual during the Beaufort Sea shallow hazard and site clearance survey, 2Aug–10 Oct 2010. Estimates were based on "corrected" non-seismic and seismic densities. All polar bears were observed on ice and these take estimates would apply only to animals in water.

Seasonal Period and Exposure level in dB re 1µPa (rms)	Non-seismic Densities		Seismic Densities	
	Individuals	Exposures per Individual	Individuals	Exposures per Individual
Jul-Aug				
≥160	1*	5	-	NA
≥170	1*	3	-	NA
≥180	1*	1	-	NA
≥190	1*	1	-	NA
Sep-Oct				
≥160	1*	9	-	NA
≥170	1*	4	-	NA
≥180	1*	1	-	NA
≥190	1*	1	-	NA
Survey Totals				
≥160	1*	5 to 9	-	NA
≥170	1*	3 to 4	-	NA
≥180	1*	1	-	NA
≥190	1*	1	-	NA

"1*" indicates number of individuals was decimal value between 0 and 1

"-" indicates <500 km (<311 mi) of observer effort within the density bin and no sightings during seismic periods

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6. BEAUFORT SEA AERIAL MARINE MAMMAL MONITORING RESULTS[1]

Introduction

An aerial monitoring program for marine mammals was conducted from 16 Jul to 9 Oct 2010 in support of seismic exploration activities by Shell Offshore, Inc. (Shell) in the Alaskan Beaufort Sea. Surveys were flown to meet monitoring and mitigation requirements and obtain detailed data on the occurrence, distribution, and movements of marine mammals, particularly bowhead whales, in the seismic survey areas and nearby waters.

Typically, bowhead whales migrate eastward through the Alaskan Beaufort Sea in the spring to reach feeding grounds in the Canadian Beaufort Sea (Braham et al. 1984; Moore and Clarke 1989; Moore and Reeves 1993). Abundance in the Alaskan Beaufort Sea in summer tends to be low and behaviors at this time consist mainly of slow or moderate eastward travel (Moore and Reeves 1993). In late summer and fall, however, bowheads begin a westward migration from Canadian feeding grounds to wintering areas off the Siberian coast (Bogoslovskaya et al. 1982). On occasion, whales linger in Alaskan waters to feed, resulting in higher sighting rates at this time (Würsig et al. 2002). In general however, peak sighting rates tend to occur in mid–Sep and decline through Oct (Miller et al. 2002).

Previous studies have shown that migrating bowhead whales have avoided seismic operations at received levels of 116–135 dB re 1 µPa (*rms*)[*] (Miller et al. 1999; Richardson et al. 1999). The Incidental Harassment Authorization (IHA) issued to Shell by NMFS required aerial monitoring of the ≥160 dB zone of the seismic survey area for bowhead and gray whales and the ≥120 dB isopleths for bowhead cow/calf pairs. If four or more bowhead cow/calf pairs were sighted within the ≥120 dB isopleth, the aerial survey crew was required to notify marine mammal observers (MMOs) on the seismic vessel (*Mt. Mitchell*) that a shut down of operations was required. Aerial observers were also required to notify MMOs on the seismic vessel and request a shut down of operations if an aggregation of 12 or more non-migrating bowhead or gray whales were sighted within the ≥160 dB isopleth during aerial surveys. These notifications allowed MMOs on the vessels to implement these specific mitigation procedures required by the IHA.

During fall, migrating bowhead whales have been reported to avoid areas within 20 km (12 mi) of seismic activities, and to exhibit subtle behavioral reactions at greater distances (Richardson et al. 1986; Koski and Johnson 1987; Ljungblad et al. 1988; Richardson and Malme 1993; Miller et al. 1999). Hence, bowhead sighting rates may be lower during seismic activities than in non–seismic periods, particularly in the immediate vicinity of seismic activities. Furthermore, migrating whales might be expected to alter their headings, resulting in increased distances from seismic operations (by moving either farther offshore or closer to shore) in areas near and perhaps west (‘downstream’) of the seismic prospect. Alternatively, feeding whales can be more tolerant to seismic sounds when high food concentrations are available and therefore may not alter their position in response to seismic activity (Miller et al. 2005). When possible, behavioral data were collected during sightings and in addition to data on distribution and sighting rates, behavioral observations are presented here in order to examine evidence for possible shifts in bowhead behavior and distribution in relation to seismic activity.

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[1] By John Brandon and Tannis Thomas

[*] Hereafter, units of dB re 1 µPa (*rms*) are simply referred to as “dB”

Beluga whales also have the potential to be negatively affected by seismic survey activity because they can hear seismic sounds (Richardson et al. 1995; Richardson and Würsig 1997). However, little is known about specific reactions of this species to seismic activities, and it has been suggested that because belugas migrate at great distances offshore during the fall, they are unlikely to be strongly affected by seismic exploration (Richardson 1999). To help understand patterns of beluga occurrence and behavior in the study area, sightings data for this species are also examined and presented here.

Objectives

The objectives of the aerial survey program were to:

- advise operating vessels of the presence of marine mammals, particularly bowhead whale cow/calf pairs and aggregations of 12 or more non-migrating gray or bowhead whales, near the operation to meet the requirements of the IHA issued by NMFS and the Letter of Authorization (LOA) issued by USFWS;
- collect and report information on the distribution, abundance, direction of travel, and activities of marine mammals near the seismic operations with special emphasis on bowhead whales;
- support regulatory reporting related to the estimation of impacts of seismic operations on marine mammals;
- document the extent, duration, and location of any bowhead whale deflections in response to seismic activities.

Methods

Study Area and Data Stratification

Aerial surveys in 2010 were located at two sites in the central Beaufort Sea: Camden and Harrison bays (Fig. 6.1). The survey effort in Harrison Bay was performed in conjunction with Shell shallow hazards seismic operations. No seismic activity occurred in Camden Bay during the open-water season of 2010, and hence aerial survey effort was a secondary priority in Camden Bay and more limited than in Harrison Bay. However, the results of the Camden Bay surveys are presented here because of the geographic proximity of that survey area to the seismic activity, and hence the potential for that data to provide comparative information.

For the Harrison Bay surveys, analyses focused on identification of bowhead whale response to seismic activities. This data set was divided into three spatial sub-areas (west, central, and east; Fig. 6.1) and four seismic states (described below under ‘Spatial differences’ and ‘Seismic state’) to assess cetacean responses to seismic survey work. For Harrison Bay, summaries of survey effort and sightings were compiled by season, where summer and fall were defined as before or after the start of Sep. The only survey effort in Camden Bay occurred during the summer season.

Stratifying by season potentially allowed for a comparison between animals which may have been summer residents or late summer migrants, and those which might have been early fall migrants. Furthermore, because estimates of ensonified areas were available for each season, this approach also addressed a potential source of bias in the estimate of individuals exposed to seismic sounds (see ‘Estimated Exposures’ below). By stratifying by season, it was not necessary to assume a constant average density in the survey area for both summer and fall.

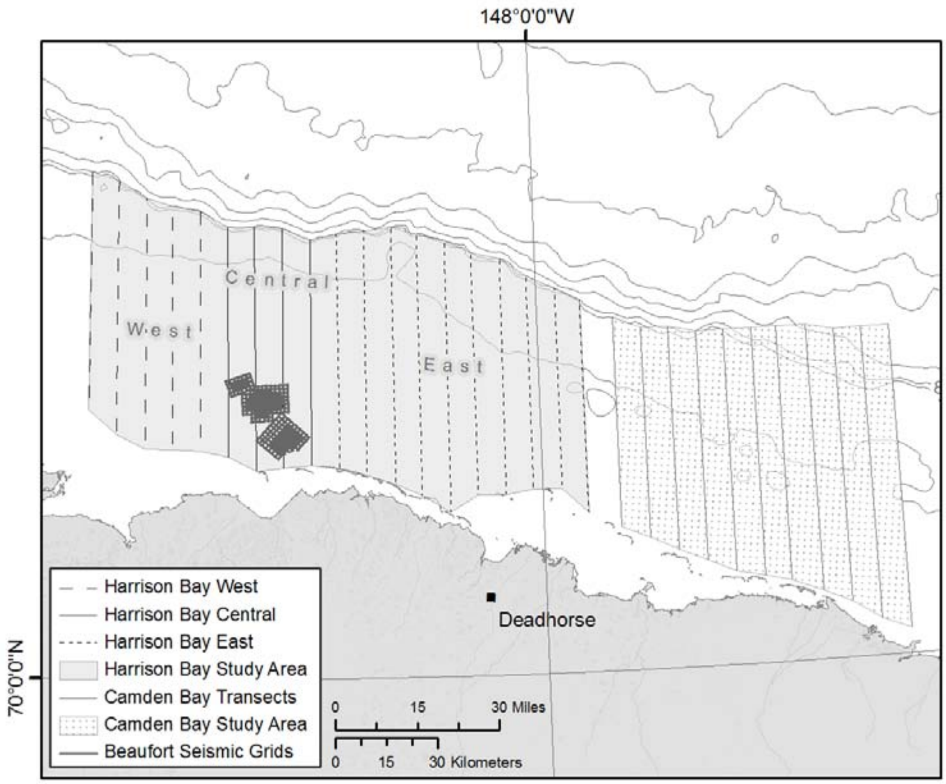

FIGURE 6.1. Aerial survey areas and transect lines in the Alaskan Beaufort Sea surveyed during 16 Jul - 9 Oct 2010. The Shell shallow hazard seismic survey area and aerial survey sub-areas (west, central and eas t) in Harrison Bay are also shown.

Surveys in the Harrison Bay Area

Aerial surveys were conducted in the Harrison Bay area during 16 Jul -9 Oct in support of shallow–hazard seismic activities at the Como, Cornell North and Mauya prospects. The survey area consisted of 19 transects varying in length from 59.9 km (32.3 mi) to 81.2 km (43.8 mi), with a total transect length of 1356.7 km (732.2 mi) and a total survey area of 24,990 km^2 (9,648 mi^2; Fig. 6.1).

Surveys of the Camden Bay Area

Aerial surveys were conducted in the Camden Bay area from 22 July through 29 Aug (Fig. 6.1). The survey area consisted of 10 transects varying in length from 62.6 km (33.8 mi) to 90.8 km (49.0 mi), with a total transect length of 759.4 km (409.8 mi). The total survey area (encompassing all transects) was 15,365 km^2 (5,932 mi^2).

Survey Procedures

Surveys were conducted in a DHC–300 Twin Otter aircraft, operated by Bald Mountain Air. The aircraft was specially modified for survey work including upgraded engines, a STOL kit to allow safer flight at low speeds, wing–tip fuel tanks, an internal auxiliary tank for part of the season, multiple GPS navigation systems, bubble windows for primary observers, and 110 V AC power for survey equipment. Surveys were conducted at an altitude of 305 m (1000 ft) above sea level and at a groundspeed of approximately 204 km/hr (110 knots). Fuel capacity and weather conditions determined flight duration. Several early season surveys were flown at 1500 ft (through 5 Aug), prior to receiving the IHA and explicit clearance to fly at 1000 ft from NMFS. Additionally, one survey was flown at 1500 ft (after the IHA was received) in Camden Bay on the 29 August in order to avoid potential disruption of Nuiqsut whalers' activities at Cross Island.

Two primary observers and up to two secondary observers sat at bubble windows on opposite sides of the aircraft and scanned the water within approximately 2 km (1.2 mi) of the aircraft for marine mammals. When a marine mammal was sighted, observers dictated into a digital voice recorder the species, number of individuals, sighting cue, age class (when determinable), activity, heading, swimming speed category (if relevant), and inclinometer reading. The inclinometer reading was recorded when the animal's location was perpendicular to the path of the aircraft, allowing calculation of lateral distance from the aircraft trackline. A GPS position was also marked at this time by the computer operator (see *Data Recording* below).

In addition to marine mammal sightings, each observer recorded the time, sightability (subjectively classified as excellent, good, moderately impaired, seriously impaired, or impossible), sea conditions (Beaufort wind force), ice cover (percentage), ice type, slush cover (percentage), and sun glare (none, little, moderate, or severe) at 2–min intervals along transects, and at the end of each transect. These provided data in units suitable for statistical summaries and analyses of effects of these variables on the probability of detecting animals (see Davis et al. 1982; Miller et al. 1999; Thomas et al. 2002).

Data Recording

An additional observer onboard the aircraft entered data from primary and secondary observers into a laptop computer and also searched for marine mammals during periods when data entry was not necessary. This observer entered transect starts and stops, 2–min intervals at which environmental data were collected, and sightings into the GPS–linked laptop. These data and additional details about environmental variables and each sighting were simultaneously recorded on digital voice recorders by the primary observers for backup, validation, and later entry into the survey database. At the start of each transect, the data recorder also entered the transect start time, ceiling height (ft), cloud cover (%), wind speed (kt), and outside air temperature (°C). N Route® position logging software was used to automatically record time and aircraft position at pre–selected intervals (typically every two seconds for straight–line transect surveys) and for all entries noted above (i.e., start, stop, each 2-min interval) for later calculation and analysis of survey effort.

Analyses of Aerial Survey Data

On–Transect Sightings and Effort

Environmental factors such as sea conditions, low clouds, and glare can affect an observer's ability to see marine mammals during aerial surveys and bias results if not accounted for during analysis. To minimize bias, environmental data were used to classify sightings and effort as on–transect or other for quantitative analyses. Sightings and effort were considered on–transect when the following criteria were met: the animal was sighted while the aircraft was flying a pre–established north–south oriented transect, Beaufort wind force was 4 or less (winds 20–30 km/h; 11–16 kt), glare covered 30% or less of the viewing field, and overall sightability was described as excellent to moderately impaired. Pinnipeds were only visible during optimal sightability conditions and were difficult to identify to species; therefore, no in–depth analyses of pinniped data were conducted.

Seismic State

Harrison Bay Area—Data from surveys of the Harrison Bay area were grouped into four seismic state categories (pre–seismic, seismic, post–seismic, and non–seismic) based on shot-files recorded on the seismic source vessel. Surveys conducted prior to the start of seismic activity were termed pre–seismic.

Data categorized as seismic were collected at times when airguns were active (including periods of ramp–up and mitigation–gun firing) and up to three minutes after airgun activity ceased. Data categorized as post–seismic were collected from three minutes to 24 hours after airgun activity ceased. This category represented the refractory period during which mammals potentially affected by seismic activities return to normal behavior and, as such, was analyzed separately. Miller et al. (1999) observed migrating bowhead whales to resume their "normal" migratory course 12 to 24 hrs after the cessation of seismic activities. All other effort was considered non–seismic. Sightings rates were compared among seismic states using a Chi–square test for goodness–of–fit.

Camden Bay Area—No seismic activity was conducted in the Camden Bay area in 2010. Hence, the data were analyzed as a single group.

Mapping

All on–transect sightings made during aerial surveys were mapped using ArcMap 9.3 (ESRI 1999–2008) and coded with different symbols to indicate seismic state and species. Each symbol represented one sighting, regardless of the number of individuals recorded within that sighting. We emphasized sightings rather than individuals for analyses because sightings were statistically independent, whereas a tally of individuals would include groups of individuals that were not independent of one another. In addition, bowheads often travel alone or in pairs and average group sizes seen during previous offshore aerial surveys of the Beaufort Sea have not been higher than 1.5 (e.g., Christie et al. 2010).

Abundance and Density

Abundance and density estimates were calculated to determine the numbers of whales potentially exposed to the various levels of sound during the seismic program. We calculated bowhead and beluga whale densities and abundances using DISTANCE software (Thomas et al. 2006) for each survey. Abundance estimates, however, were only calculated when effort was greater than 250 km (155 mi). Corrections for missed sightings at increasing distance from observers, f(0) values, were calculated by DISTANCE using the 2010 aerial sightings, except when sightings were low data from sightings in the Chukchi and Beaufort seas from 2007 and 2008 were used (Thomas et al. 2010, Christie et al. 2010). Corrections for groups that were on or near to the trackline but unavailable for detection by observers, $g(0)$ values, were based on previous research (bowhead whales $g(0) = 0.144$, Thomas et al. 2002; beluga whales $g(0) = 0.58$, Martin and Smith 1992). In addition, right truncation distances were calculated by graphing sightings and excluding sightings where the detection probability was <0.10. Left truncation distances were set at 100 ft (except for bowheads which did not show a drop off at the centerline), because animals directly below the aircraft were difficult to see. Several models were created and compared in DISTANCE, and the best fitting model, with the lowest Akaike's Information Criterion (AIC, Burnham and Anderson, 1998), was chosen. Densities were calculated for each survey individually, and bootstrapped abundance averages were then calculated for summer and fall survey periods using the Resampling Tool Add–on for Excel (Blank et al. 2000). Estimates of the average daily numbers of whales present for summer and fall periods were based on bootstrapping the daily data as a function of the amount of survey effort on any one day (i.e., estimates from days with low survey effort received less weight).

Spatial differences

To assess potential differences in the distribution of animals relative to seismic activity, the survey effort in Harrison Bay was divided into three geographical sub–areas: east, central, and west. These sub-areas were designed such that the central sub-area included the seismic survey area (see Fig. 6.1) and also such that the survey effort for each sub-area was roughly equal. This allowed for the examination of the hypothesis that bowhead whales react to seismic activity by increasing the distance from the sound source (either by moving farther offshore or closer to shore) in the central and perhaps the west sub-areas.

Effort and sightings data were divided into 5–km distance-from-shore bins, with a "0-km from shore" line approximating the shoreline or the outer edge of the barrier islands. To assess any offshore deflections, sighting rates were computed within each of these bins and plotted by seismic state.

Sightings data were divided into 5–m depth bins and plotted to investigate patterns in distribution relative to water depth. Because distance from shore and depth are strongly correlated, we would expect that patterns in sighting rates by depth would be similar to those observed for distance from shore.

Distribution Relative to the Center of the Seismic Survey Area

The distribution of mammal sightings relative to the center of the seismic survey area was calculated by plotting the seismic prospect in ArcMap 9.3 and estimating the geographical center with the measure tool. The distance between sightings and the center point of the prospect was then calculated. These distances were compared with the non–parametric Mann-Whitney U test to determine whether average distance from the center of the seismic survey area differed among seismic states.

Headings, Activities, and Speed

Headings were plotted by area and seismic state and circular-mean vector headings and circular-standard deviations were assessed with Oriana statistical software using Rayleigh tests (KCS 2008). Speeds and headings were only assessed for whales observed to be either traveling or swimming. If possible, behavior (movements or processes in which animal is engaged) and activity (a collection of behaviors that indicate the animal is working toward an overall goal such as migrating) were recorded for each sighting. Behaviors included swimming, diving, surface active (flipper or fluke slaps, splashing, etc.), and hauled out; whereas activities included feeding, traveling, socializing, resting, and milling. Due to the limited time period for which an animal was observed, it was not always possible to determine the behavior, activity, speed, and/or heading for every sighting; as a result, often only a subset of this information was collected.

Estimated Exposures

The weighted average densities of whales in the survey area for summer and fall was divided by the area of water excluding overlapping areas exposed to received sound levels ≥160 dB and ≥180 dB for each season, the resulting estimated numbers of individual whales potentially exposed during each season was then summed to calculate the overall total. Estimated number of exposures per individual was calculated as the ratio of the total area of water ensonified (including areas that were ensonified multiple times) to the area of water ensonified with overlapping areas excluded, and was taken as the average of that quantity each season. This ratio represents the number of times an individual whale (were it to never move out of the seismic area over the course of the entire season) would be exposed to seismic noise at a given level.

Results

Aerial surveys were flown over the Alaskan Beaufort Sea from 16 Jul through 9 Oct 2010; a total of 16,533 km (10,273 mi) of effort was obtained during 35 surveys. Survey effort was four times greater in Harrison Bay compared to Camden Bay (Tables 6.1 and 6.10).

Harrison Bay Area

Survey effort

Surveys were flown in the Harrison Bay area from 16 Jul to 9 Oct 2010 (Fig. 6.2). Survey effort ranged from 18 km (11 mi) to 732 km (455 mi) per survey. Ice conditions in the Harrison Bay area were relatively heavy, and may have contributed to persistent fog during much of the season, which prohibited survey effort on many days. The pre–seismic period comprised approximately one half of the total survey effort (5782 km of effort; 3593 mi) and lasted until 13 Aug, when Shell seismic survey activities began. Seismic and post–seismic periods occurred from mid–Aug until the end of the survey season (Fig. 6.2). Overall, 1870 km (1162 mi) of survey effort occurred during seismic activities, 1553 km (965 mi) during post–seismic activities, and an additional 4553 km (2829 mi) during non–seismic activities. Dates of aerial survey flights are compared with hours of vessel–based seismic data acquisition in Appendix Fig. K.1.

When compared among areas, effort was similar, though slightly higher in the central sub-area (Fig. 6.3). When assessed by 5–km (3–mi) distance-from-shore bins, survey effort was highest in the 40–45 km (25–28 mi) from shore bin (Fig. 6.4). In general, effort was relatively high up to approximately 55 km (34 mi) offshore and dropped substantially beyond 70 km (43 mi) from shore (Fig. 6.4).

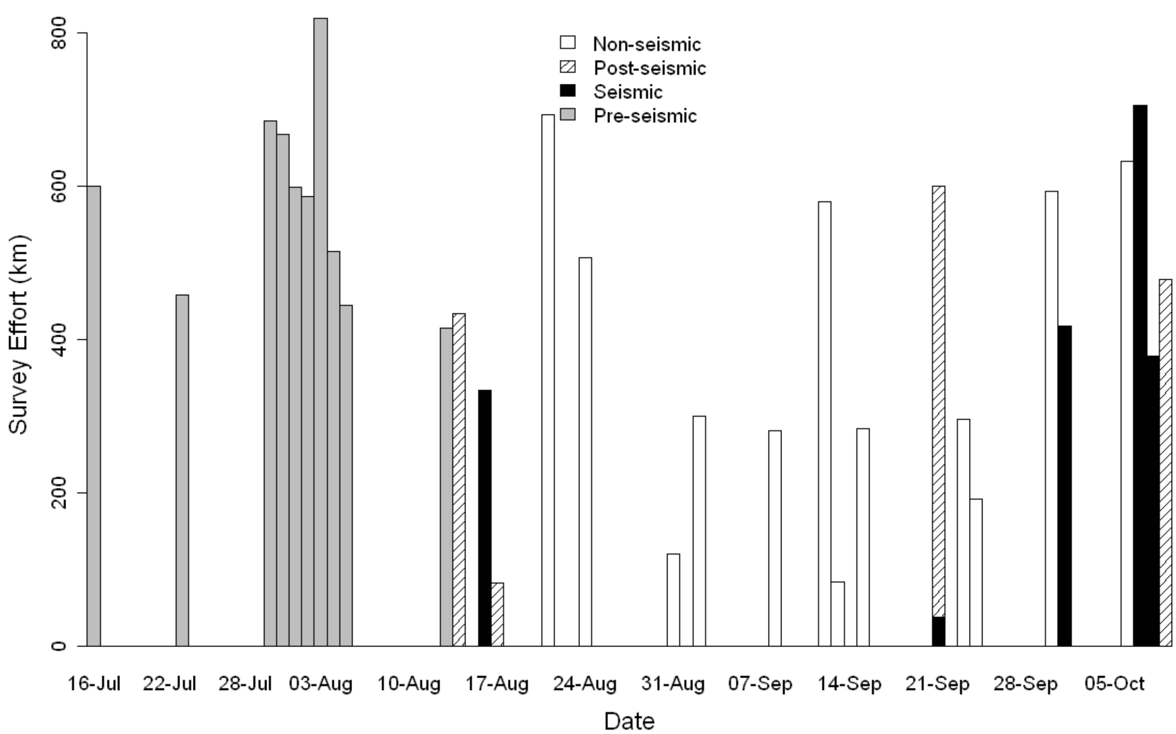

FIGURE 6.2. Survey effort by seismic state (indicated by fill pattern) in the Harrison Bay area during 16 Jul - 9 Oct 2010.

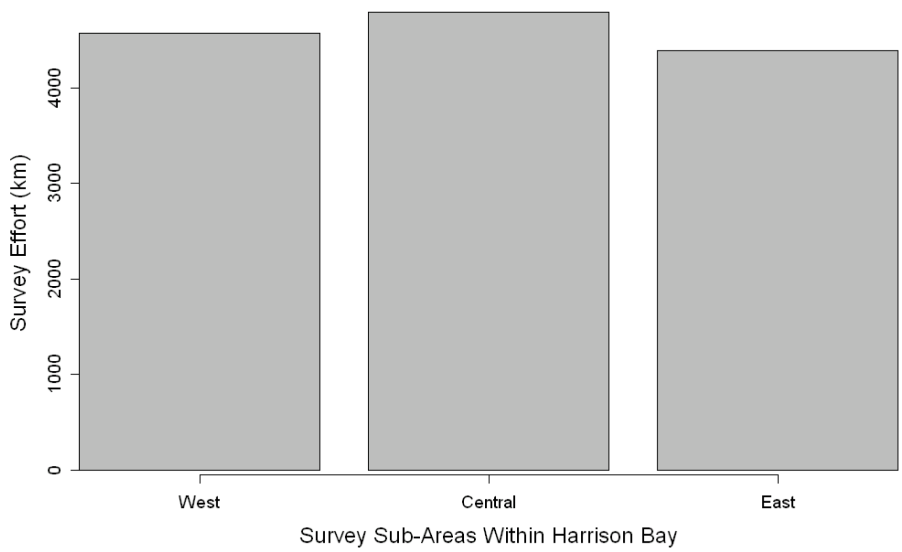

FIGURE 6.3. Aerial survey effort in west, central, and east sub-areas of the Harrison Bay area during 16 Jul - 9 Oct 2010.

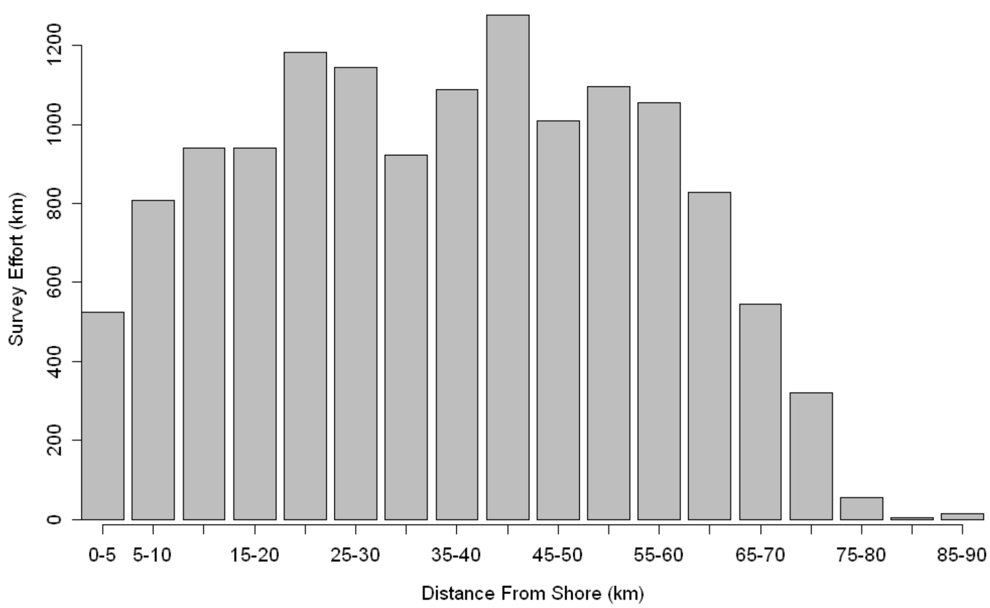

FIGURE 6.4. Aerial survey effort by 5–km distance-from-shore bins in the Harrison Bay area during 16 Jul - 9 Oct 2010.

Bowhead Whales

***Sightings and Sighting Rates*—**A total of 61 bowhead whale sightings (78 individual whales) were recorded during Shell's aerial surveys in the Harrison Bay area in 2010. However, only 28 of these sightings (37 individuals) were recorded on–transect in acceptable sightability conditions (Fig. 6.5; Table 6.1) and were used in the following analyses and discussion. Bowhead whales were observed on 39% of surveys and the overall sighting rate was 2.0 sightings/1000 km (3.28 sightings/1000 mi). Sighting rates ranged from 0–12 sightings/1000 km (0–19 sightings/1000 mi) and 0-18 individuals/1000 km (0–34 individuals/1000 mi). Bowhead whale sighting rates were highest in Sep and early Oct, with a peak sighting rate of 12 sightings/1000 km (19 sightings/1000 mi) on 1 Oct.

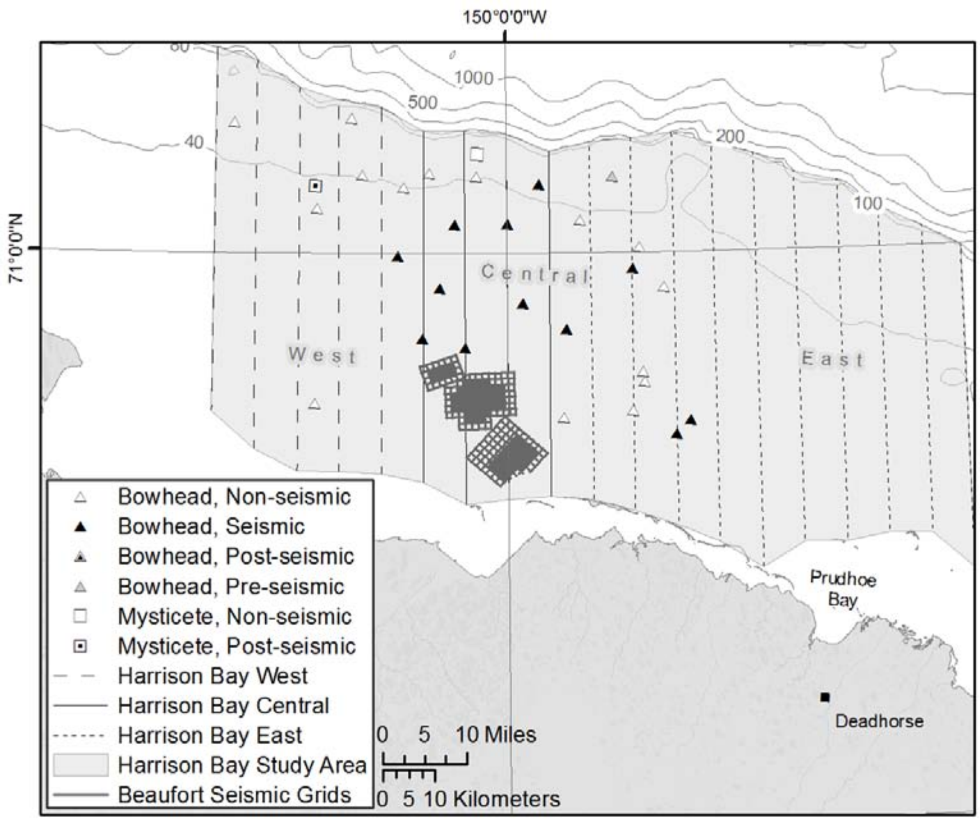

FIGURE 6.5. Bowhead whale and unidentified mysticete whale sighting locations during surveys in the Harrison Bay area 16 Jul - 9 Oct 2010. The Shell shallow hazard seismic survey area in Harrison Bay is also shown. The three prospect areas are plotted as solid polygons (north to south): Cornell North, Como and Mauya. The seismic survey lines are denoted by the grids around the main prospect area. Those lines also run across the prospect area, although the entire grid is not visible over the solid shaded prospect areas.

TABLE 6.1. Summary of aerial survey effort, sighting rates and estimated numbers of bowhead whales in the Harrison Bay area during 16 Jul - 9 Oct 2010. Numbers of sightings and individuals in parentheses were based on <500 km of effort and should be viewed with caution. Sighting rates were not calculated ("NC") when effort for an individual survey was less than 250 km (155 mi). Estimates were obtained using DISTANCE software for each individual survey. Numbers in parentheses should be interpreted with caution due to low effort (<500 km or 311 mi). Estimates include allowance for *f*(0) (as calculated by DISTANCE) and *g*(0) (value of 0.144 from Thomas et al. 2002).

Date	Survey Number	Effort (km)	Seismic State	Sightings	Individuals	Sightings / 1000 km	Individuals / 1000 km	Density (No. / 1000 km2)	Est. No. Whales	Lower CI	Upper CI
16 Jul	1	599	Pre	0	0	0.0	0.0	0	0		
23 Jul	2	458	Pre	0	0	0.0	0.0	0	0		
30 Jul	3	685	Pre	0	0	0.0	0.0	0	0		
31 Jul	4	667	Pre	0	0	0.0	0.0	0	0		
1 Aug	5	597	Pre	0	0	0.0	0.0	0	0		
2 Aug	6	586	Pre	0	0	0.0	0.0	0	0		
3 Aug	7	818	Pre	1	1	1.2	1.2	4	108	19	616
4 Aug	8	514	Pre	0	0	0.0	0.0	0	0		
5 Aug	9	444	Pre	0	0	0.0	0.0	0	0		
13 Aug	10	415	Pre	0	0	0.0	0.0	0	0		
14 Aug	11	433	Post	0	0	0.0	0.0	0	0		
16, 17 Aug	12	415	On and Post	0	0	0.0	0.0	0	0		
21 Aug	13	692	Non	0	0	0.0	0.0	0	0		
24 Aug	14	506	Non	2	2	4.0	4.0	8	200	32	1269
31 Aug	15	119	Non	0	0	NC	NC	NC	NC		
Summer Total/Average	**15**	**7947**		**3**	**3**	**0.4**	**0.4**	**1.0**	**24**	**0**	**58**
2 Sep	16	299	Non	2	3	6.7	10.0	41	1015	213	4826
8 Sep	17	281	Non	3	5	10.7	17.8	72	1800	193	16801
12 Sep	18	580	Non	2	2	3.5	3.5	14	349	90	1360
13, 15 Sep	19	366	Non	1	1	2.7	2.7	11	276	47	1612
21 Sep	20	599	On and Post	0	0	0.0	0.0	0	0		
23 Sep	21	295	Non	0	0	0.0	0.0	0	0		
24 Sep	22	191	Non	(2)	(4)	NC	NC	NC	NC		
30 Sep	23	593	Non	3	4	5.1	6.7	27	683	171	2724
1 Oct	24	417	On	5	6	12.0	14.4	58	1455	582	3635
6 Oct	25	631	Non	0	0	0.0	0.0	0	0		
7 Oct	26	704	On	5	6	7.1	8.5	34	862	370	2009
8 Oct	27	378	On	2	3	5.3	7.9	32	803	142	4538
9 Oct	28	478	Post	0	0	0.0	0.0	0	0		
Fall Total/Average	**13**	**5812**		**25**	**34**	**4.1**	**5.3**	**21.6**	**542**	**267**	**843**
Season Total/Average	**28**	**13759**		**28**	**37**	**2.0**	**2.7**				

Bowhead sighting rates were calculated for surveys conducted during pre–seismic, seismic, post–seismic, and non–seismic periods. Overall bowhead whale sighting rates (all areas combined) were highest during the seismic period (6 sightings/1000 km; 10 sightings/1000 mi) and lowest during post–seismic periods (0 sightings/1000 km; 0 sightings/1000 mi; Table 6.2). The differences in the sighting rates across all seismic states were significantly different than would be expected by chance, given the overall average sighting rate across seismic states (Chi–square test, $p < 0.05$, Table 6.3). This result is driven by the higher than expected sighting rates during seismic activity (Table 6.2).

When we examined sighting rates by area within Harrison Bay, sighting rates were lowest in the west; however, differences in bowhead sighting rates among the three sub-areas were not statistically significant (Chi–square test, $p > 0.05$, Table 6.4). In the central area (where seismic activities occurred), sighting rates appeared to be higher during the seismic period than in other seismic states, however, the low sample size precluded statistical analyses for this subset of the data.

Abundance and Density**—**Numbers of bowheads present within the aerial survey area in Harrison Bay from 16 Jul through 9 Oct 2010 were estimated using DISTANCE software (Table 6.1). Approximately 24 (weighted average based on data in Table 6.1, s.d.= 15.4, 95% C.I.= 0–58) bowhead whales were estimated to have been present in the aerial survey area each day during the summer season (Jul through Aug), and 542 (s.d.= 149.5, 95% C.I.= 267–843) were estimated to have been present during the fall season (Sep through Oct). Estimates during individual surveys ranged from 0 to 1800 individuals, with highest numbers on 8 Sep. Some estimates should be interpreted with caution due to low survey effort (<500 km). In addition, survey effort was too low to calculate a bowhead abundance estimate for one survey.

TABLE 6.2. Bowhead whale sightings and sighting rates during aerial surveys in the Harrison Bay area by seismic state during 16 Jul - 9 Oct 2010.

		Pre-seismic	Seismic	Post-seismic	Non-Seismic	Total or Average
West	Effort	1953	760	453	1408	4574
	Sightings	0	1	0	5	6
	Individuals	0	2	0	6	8
	Sightings / 1000 km	0	1.3	0	3.6	1.3
	Individuals / 1000 km	0	2.6	0	4.3	1.7
Central	Effort	2055	672	499	1566	4792
	Sightings	0	8	0	3	11
	Individuals	0	9	0	6	15
	Sightings / 1000 km	0	11.9	0	1.9	2.3
	Individuals / 1000 km	0	13.4	0	3.8	3.1
East	Effort	1774	438	601	1580	4393
	Sightings	1	3	0	7	11
	Individuals	1	4	0	9	14
	Sightings / 1000 km	0.6	6.8	0	4.4	2.5
	Individuals / 1000 km	0.6	9.1	0	5.7	3.2
All areas	Effort	5782	1870	1553	4553	13759
	Sightings	1	12	0	15	28
	Individuals	1	15	0	21	37
	Sightings / 1000 km	0.2	6.4	0	3.3	2.0
	Individuals / 1000 km	0.2	8.0	0	4.6	2.7

TABLE 6.3. Chi–square test comparing differences in number of bowhead whale sightings by seismic state during aerial surveys in the Harrison Bay area during 16 Jul - 9 Oct 2010.

Area		Pre-seismic	Seismic	Post-seismic	Non-seismic	$\chi2$	One-tailed *p*-value
All	Sightings (obs.)	1	12	0	15	34.20	<< 0.05
	Sightings (exp.)	11.8	3.8	3.2	9.3		
	Effort (km)	5782	1870	1553	4553		

TABLE 6.4. Chi–square test comparing bowhead sighting rates in the west, central and east sub-areas during aerial surveys in the Harrison Bay area during 16 Jul - 9 Oct 2010.

Area		West	Central	East	$\chi2$	One-tailed *p*-value
All	Sightings (	6	11	11	1.810	0.613
	Sightings (	9.3	9.8	8.9		
	Effort (km	4574	4792	4393		

Distance from Shore and Depth—For all sub-areas combined, peak bowhead sighting rates were observed at distances 60–65 km (37–40 mi) from shore during the 2010 aerial surveys in Harrison Bay (Fig. 6.6). This pattern was most evident in the west and central sub-areas; the distribution of distance from shore was more uniform in the east sub-area, including several sightings within 20 km of shore. In the central area, the sighting rates during seismic activity were higher closer to shore than they were during non-seismic periods. There were too few sightings (one for pre-seismic and zero for post-seismic) to be able to discern any patterns in distance from shore for those seismic states. Values for all distance from shore bins are shown in Appendix Table K.1.

Observed water depth where bowhead whales were sighted varied from 5 to 21 m (17 to 68 ft). The majority of sightings were at depths between 5 - 10 m (16 - 33 ft; Fig. 6.7).

Distribution Around Seismic Operations—Sufficient numbers of sightings were not available during pre-seismic and post-seismic states to test for differences in the average distance of bowheads from the seismic survey center at those times. However, it was possible to test for a difference in bowhead distance from the center of the seismic survey area between seismic and non-seismic states. Test results suggested that bowhead sightings during seismic activity were closer to the center of the seismic survey area than they were during non-seismic periods ($p = 0.02 < 0.05$; Figs. 6.2 and 6.6). Details on bowhead sightings made during seismic periods are presented in Appendix Table K.2.

Activities—Specific activities were recorded for 21 bowhead whale sightings. Fourteen sightings were of traveling whales, four were of milling whales, and one sighting each was observed for resting, socializing and breaching. (Fig. 6.8). There were no activities (or sightings) recorded during post-seismic periods (Table 6.2), and only one recorded activity during pre-seismic, which was of a resting animal.

Speed—Most observations of movement speed were of animals moving slowly (n=14). Six animals were observed moving at a moderate speed, and one animal was observed moving fast. There did not appear to be any relationship between speed and seismic activity; the numbers of observations for each speed were similar for each seismic state (Fig. 6.9).

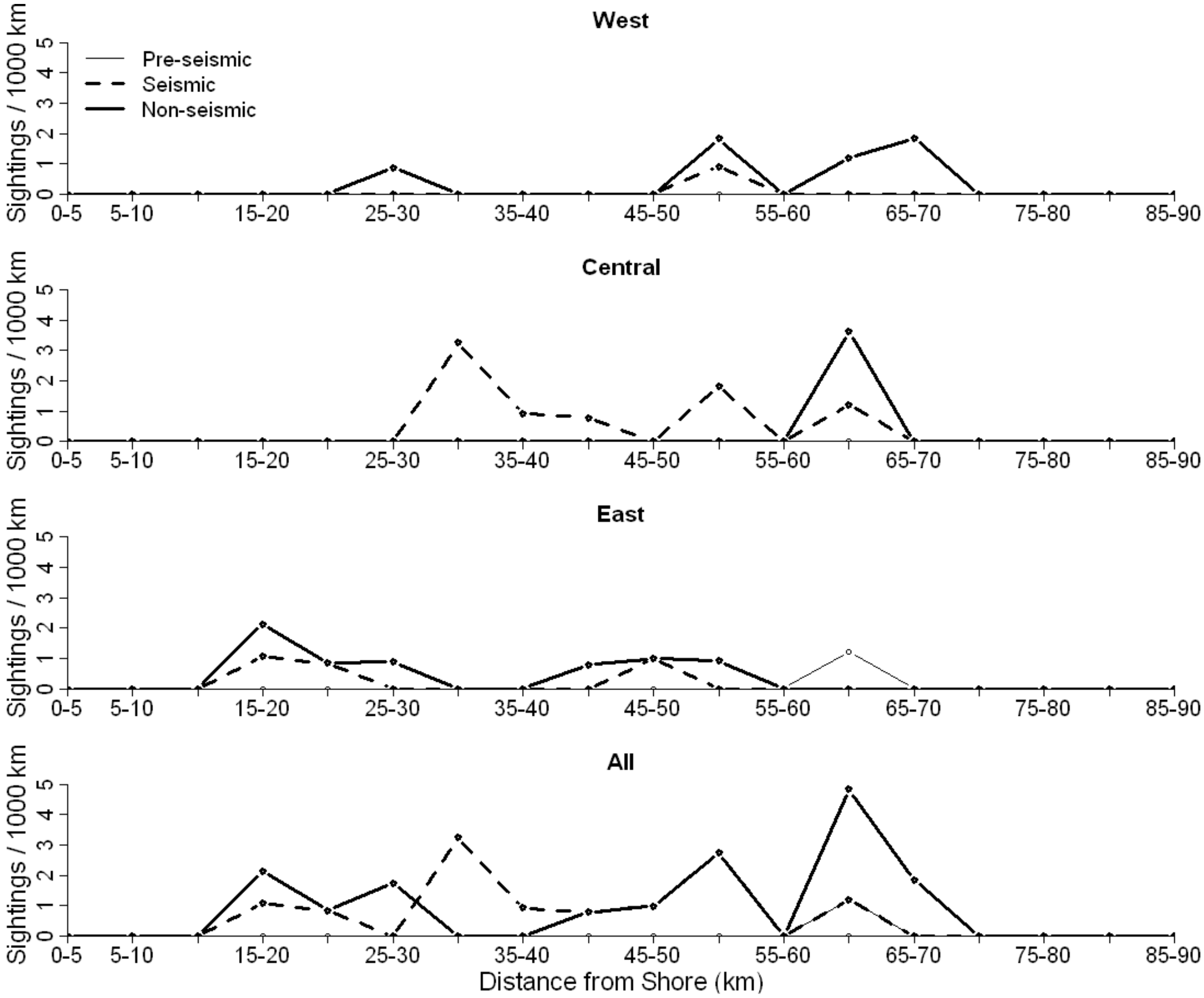

FIGURE 6.6. Bowhead sighting rates are shown as a function of the distance from shore during aerial surveys in survey sub-areas of Harrison Bay during 16 Jul - 9 Oct 2010. The bottom plot shows those rates calculated over the entire survey area. No sightings were made during post-seismic states.

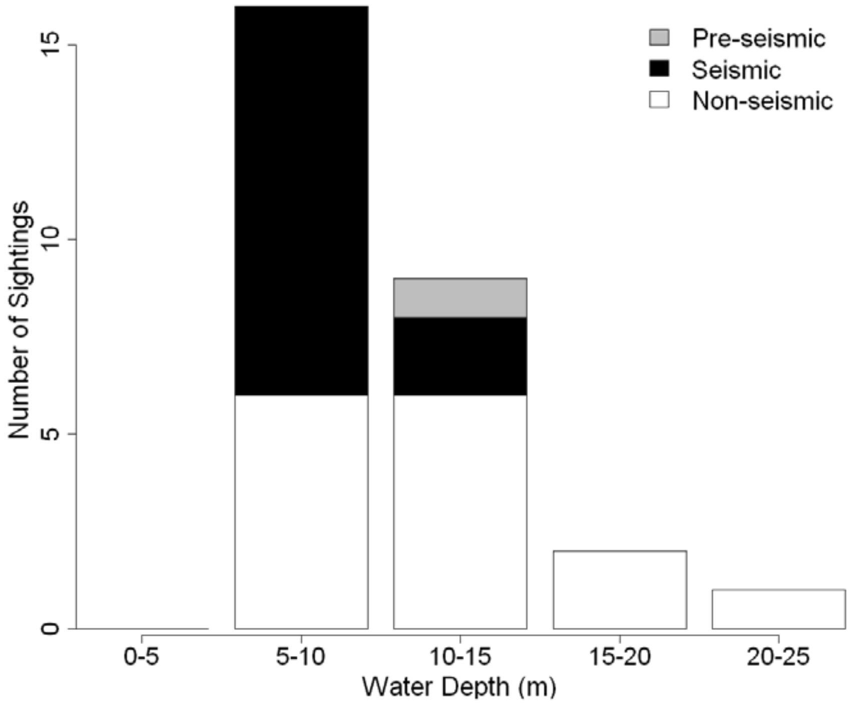

FIGURE 6.7. Number of bowhead whale sightings at 5–m (16–ft) water depth intervals during aerial surveys during 16 Jul - 9 Oct 2010. Seismic state at the time of sightings is indicated by fill pattern. There were no sightings in water depth between 0-5m.

Headings—We assumed bowheads that were swimming or traveling were migrating and compared their headings during different seismic states. Headings of 25 bowhead whales were recorded, 11 of which were sighted during seismic periods (mean heading = 274ºT; circular SD = 69ºT; $p < 0.07$), and 13 during a non-seismic period (mean heading = 309ºT; circular SD = 62ºT $p = 0.015 < 0.05$; Fig. 6.10). Only one heading (302ºT) was recorded during pre-seismic periods and no headings were recorded during post-seismic periods. For all observations combined, the average heading was 295ºT, with a circular standard deviation of 65°T ($p<<0.01$).

Average headings were similar between summer and fall (Fig. 6.10), although the limited (n=3) number of observations during the summer precluded any confidence in that comparison. During fall the average heading was 296ºT, with a circular standard deviation of 71°T ($p = 0.008 < 0.05$).

TABLE 6.5. Minimum, maximum and mean distance (km) of bowhead whale sightings from the center of the seismic prospect by seismic state in the Harrison Bay area, 16 Jul through 9 Oct 2010. The difference between the distance distributions during seismic and non-seismic periods was examined using the Mann-Whitney U test.

Seismic State	Sightings	Distance from Prospect Center (km)			Two-tailed p-value
	n	Min.	Max.	Mean	
Pre-seismic	1	--	--	50.55	
Post-seismic	0	--	--	--	
Seismic	12	10.17	43.64	29.41	0.02
Non-seismic	15	16.93	71.01	41.69	

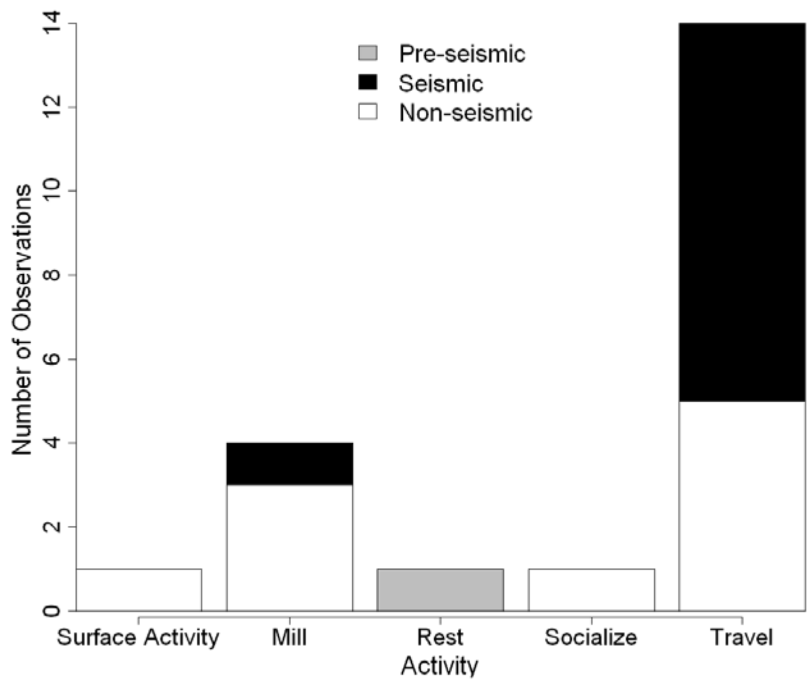

FIGURE 6.8. Observed activities of bowhead whales sighted during aerial surveys from 16 Jul - 9 Oct 2010 in the Harrison Bay area. Seismic state at the time of sighting is indicated by the fill pattern.

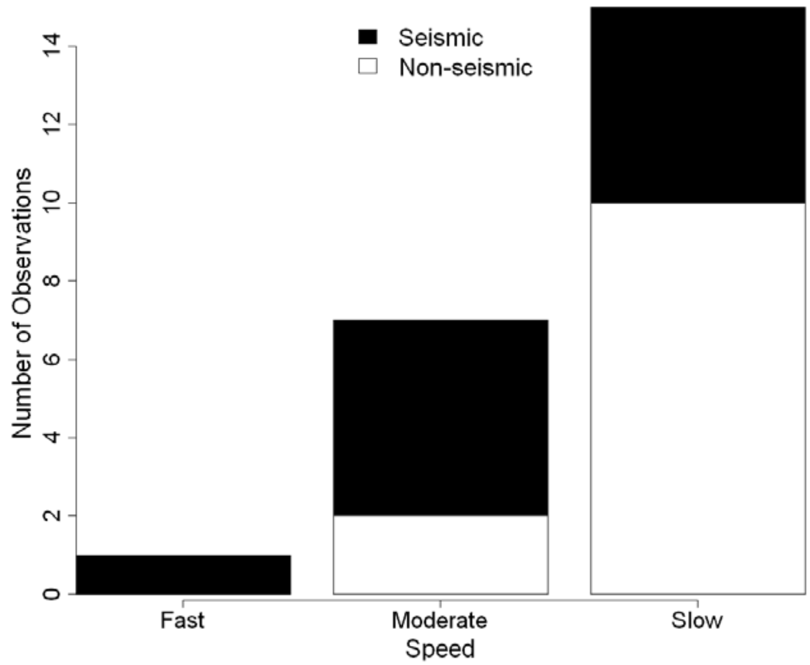

FIGURE 6.9. Observed speeds of bowhead whales sighted during aerial surveys during 16 Jul - 9 Oct 2010 in the Harrison Bay area. Seismic state at the time of sighting is indicated by the fill pattern. No recorded observations of swim speeds were made for pre- or post-seismic sightings.

Mitigation Measures Implemented**—**As required by the 2010 IHA issued by the NMFS, mitigation was necessary if an aggregation of 12 or more bowhead whales was observed within the ≥160 dB radius, or if four or more cow/calf pairs were observed within the ≥120 dB radius. These criteria were never met, and therefore no shut-downs were initiated based on aerial observations.

Estimated Number of Bowheads Present and Potentially Affected**—**Two received level criteria have been specified by NMFS as relevant in estimating cetacean "take by harassment", though exposures to these sound levels may not necessarily result in a biologically significant effect:

- 180 dB , above which there is concern about possible temporary effects on hearing;
- 160 dB, above which avoidance and other behavioral reactions may occur.

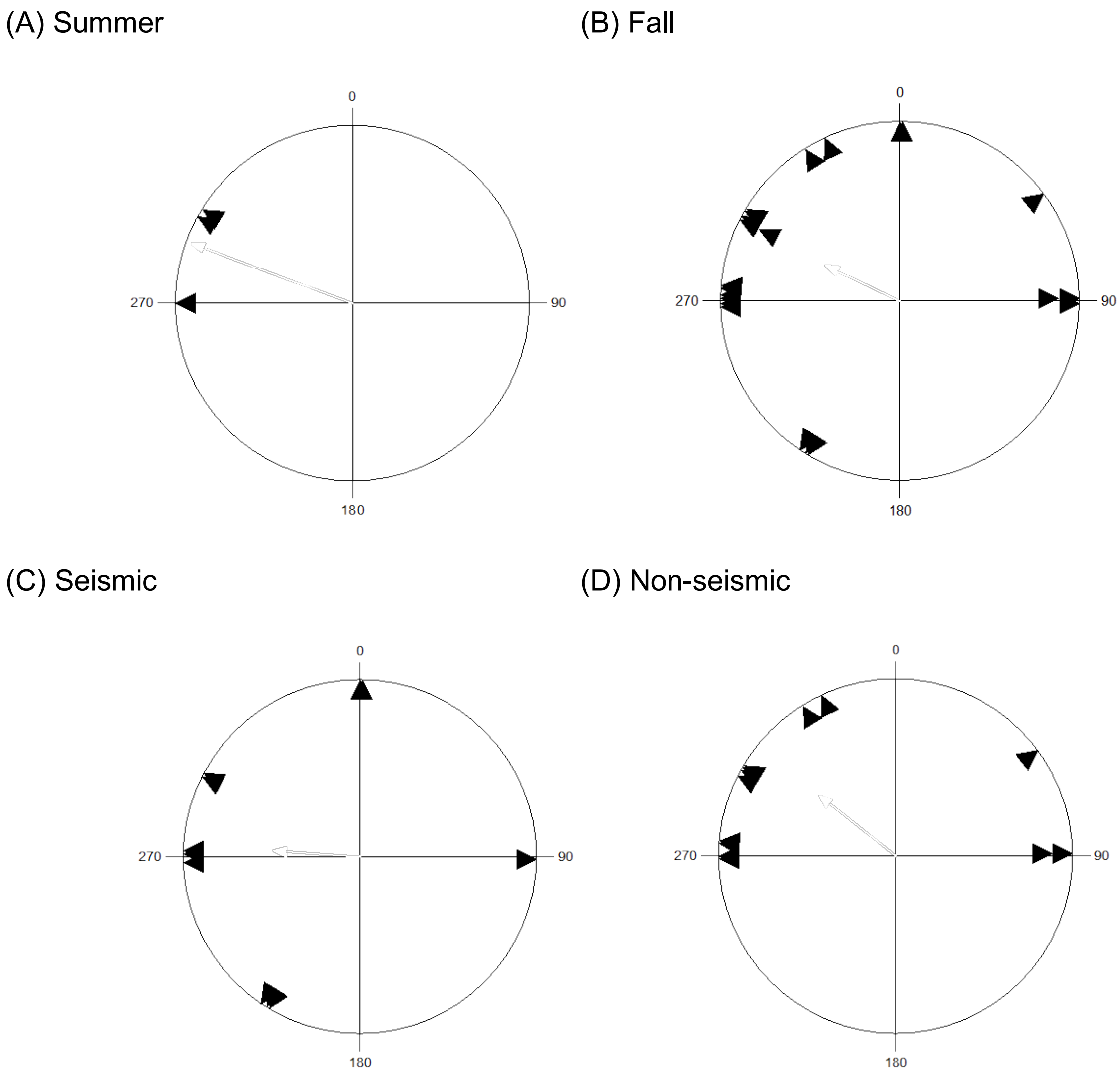

FIGURE 6.10. Headings of bowhead whales during: (A) Summer; (B) Fall; (C) Seismic periods, and; (D) Non-seismic periods in the Harrison Bay area during 16 Jul - 9 Oct 2010. Only one heading (302°) was recorded during pre-seismic surveys and no headings were recorded during post-seismic surveys. The circular average heading and deviation are plotted as a vector (shorter vectors represent larger variability in headings).

Using a weighted average of density estimates for bowhead whales from surveys conducted in the Harrison Bay area calculated with DISTANCE software and the total area of water ensonified by survey activities calculated with ArcMap 9.3, the numbers of potential bowhead exposures to received sound levels were estimated for each of the received level criteria, assuming no avoidance of the survey area (Table 6.6).

TABLE 6.6. Estimated number of individual bowhead whales exposed to received sound levels ≥180 and ≥160 dB during seismic survey activities by Shell in the Harrison Bay area and average number of exposures per individual during 16 Jul - 9 Oct 2010.

Exposure level in dB re 1 uPa (rms)	Individuals Exposed	Exposures per Individual
≥ 180 dB	3	1.3
≥ 160 dB	27	20.2

<u>Beluga Whales</u>

Sightings and Sighting Rates.—A total of 25 beluga whale sightings (32 individual whales) were recorded during surveys in Harrison Bay. Eight of these sightings (10 individuals) were recorded on–transect in acceptable sightability conditions (Table 6.7, Fig. 6.11; see *Methods* for definitions of sightability and on–transect) and are used in the following analyses and discussion. During the summer months (Jul through Aug), beluga whales were observed on 33% of surveys at an average rate of 1 sighting/1000 km. We observed 0–4 individuals per survey, with corresponding sighting rates from 0–5 sightings/1000 km (0–8 sightings/1000 mi) and 0 to 8 individuals/1000 km (0–13 individuals/1000 mi). Beluga whales were not observed during Sep–Oct.

Abundance and Density—Estimates of numbers of belugas in the Harrison Bay study area ranged from 0 to 325 individuals during the summer months (Table 6.8). Corresponding densities ranged from 0 to 13 individuals/1000 km^2 (0 to 21 individuals/1000 mi^2) during the summer.

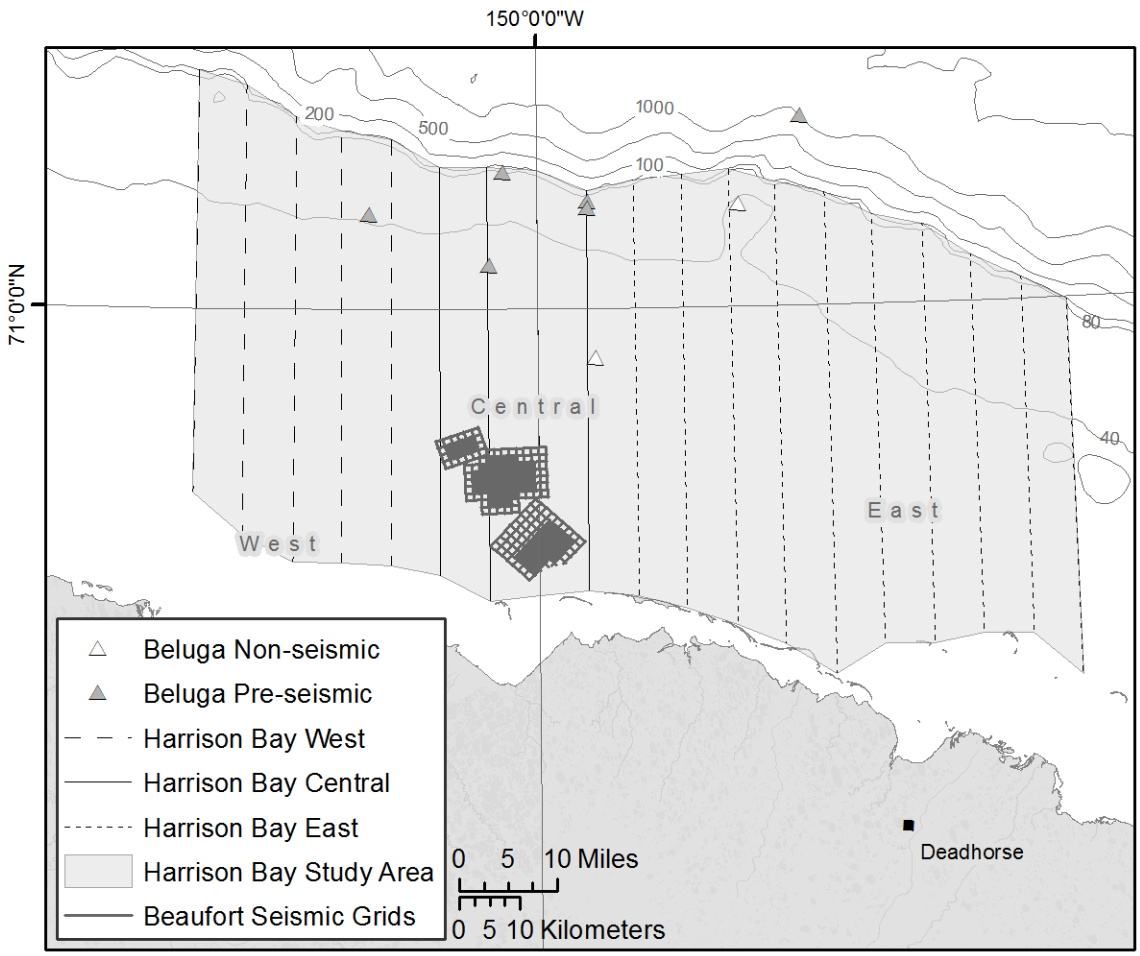

FIGURE 6.11. Beluga whale sighting locations during surveys in Harrison Bay are shown by seismic state. No beluga sightings were recorded after the start of Sep.

TABLE 6.7. Summary of aerial survey effort and sighting rates for beluga whales in Harrison Bay from 16 Jul through 9 Oct 2010. Numbers of sightings and individuals in parentheses were based on <500 km of effort and s hould be viewed with caution. Sighting rates were not calculated (“NC”) when effort was less than 250 km (155 mi).

Date	Survey Number	Effort	Sightings	Individuals	Sightings /1000km	Individuals /1000km
16 Jul	1	599	3	3	5.0	5.0
23 Jul	2	458	(0)	(0)	0.0	0.0
30 Jul	3	685	0	0	0.0	0.0
31 Jul	4	667	0	0	0.0	0.0
1 Aug	5	597	1	1	1.7	1.7
2 Aug	6	586	0	0	0.0	0.0
3 Aug	7	818	1	1	1.2	1.2
4 Aug	8	514	0	0	0.0	0.0
5 Aug	9	444	(1)	(1)	2.3	2.3
13 Aug	10	415	(0)	(0)	0.0	0.0
14 Aug	11	433	(0)	(0)	0.0	0.0
16, 17 Aug	12	415	(0)	(0)	0.0	0.0
21 Aug	13	692	0	0	0.0	0.0
24 Aug	14	506	2	4	4.0	7.9
31 Aug	15	119	(0)	(0)	NC	NC
Summer Total/Average	**15**	**7947**	**8**	**10**	**1.0**	**1.3**
2 Sep	16	299	(0)	(0)	0.0	0.0
8 Sep	17	281	(0)	(0)	0.0	0.0
12 Sep	18	580	0	0	0.0	0.0
13, 15 Sep	19	366	(0)	(0)	0.0	0.0
21 Sep	20	599	0	0	0.0	0.0
23 Sep	21	295	(0)	(0)	0.0	0.0
24 Sep	22	191	(0)	(0)	NC	NC
30 Sep	23	593	0	0	0.0	0.0
1 Oct	24	417	(0)	(0)	0.0	0.0
6 Oct	25	631	0	0	0.0	0.0
7 Oct	26	704	0	0	0.0	0.0
8 Oct	27	378	(0)	(0)	0.0	0.0
9 Oct	28	478	(0)	(0)	0.0	0.0
Fall Total/Average	**13**	**5812**	**0**	**0**	**0.0**	**0.0**

TABLE 6.8. Estimated numbers of beluga whales in the survey area in Harrison Bay, 16 Jul through 9 Oct 2010. Estimates obtained using DISTANCE software for each individual survey. Numbers in parentheses should be interpreted with caution due to low effort (<500 km or 311 mi). Estimates include allowance for *f*(0) (as calculated by DISTANCE) and *g*(0).

Date	Survey Number	Effort (km)	Sightings	Individuals	Density (No. / 1000 km2)	Est. No. Whales	95 % CI	
16 Jul	1	599	3	3	6	153	35	681
23 Jul	2	458	(0)	(0)	(0)	(0)		
30 Jul	3	685	0	0	0	0		
31 Jul	4	667	0	0	0	0		
1 Aug	5	597	1	1	2	51	7	362
2 Aug	6	586	0	0	0	0		
3 Aug	7	818	1	1	1	37	8	172
4 Aug	8	514	0	0	0	0		
5 Aug	9	444	(1)	(1)	3	69	12	401
13 Aug	10	415	(0)	(0)	(0)	(0)		
14 Aug	11	433	(0)	(0)	(0)	(0)		
16, 17 Aug	12	415	(0)	(0)	(0)	(0)		
21 Aug	13	692	0	0	0	0		
24 Aug	14	506	2	4	13	325	55	1905
31 Aug	15	119	(0)	(0)	NC	NC		
Summer Total/Average	**15**	**7947**	**8**	**10**	**1.8**	**45**	**8**	**95**
2 Sep	16	299	(0)	(0)	(0)	(0)		
8 Sep	17	281	(0)	(0)	(0)	(0)		
12 Sep	18	580	0	0	0	0		
13, 15 Sep	19	366	(0)	(0)	(0)	(0)		
21 Sep	20	599	0	0	0	0		
23 Sep	21	295	(0)	(0)	(0)	(0)		
24 Sep	22	191	(0)	(0)	NC	NC		
30 Sep	23	593	0	0	0	0		
1 Oct	24	417	(0)	(0)	(0)	(0)		
6 Oct	25	631	0	0	0	0		
7 Oct	26	704	0	0	0	0		
8 Oct	27	378	(0)	(0)	(0)	(0)		
9 Oct	28	478	(0)	(0)	(0)	(0)		
Fall Total/Average	**13**	**5812**	**0**	**0**	**0.0**	**0**		

Distance from Shore and Depth—Peak beluga sighting rates were observed at distances >75 km (>47 mi) from shore (Fig. 6.12) during this survey period. Beluga sighting rates were highest in the northern portion of the survey area at depths > 100 m (328 ft).

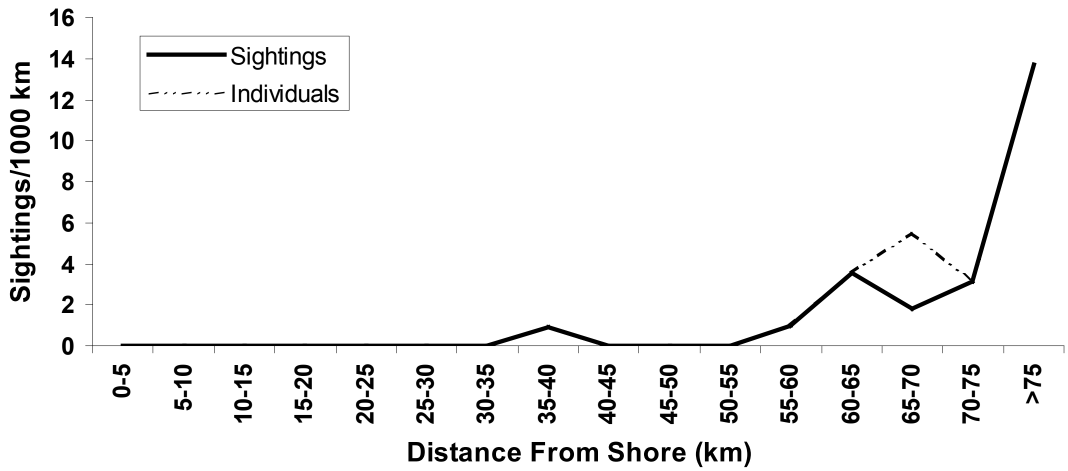

FIGURE 6.12. Beluga sighting rates within 5–km distance-from-shore bins during aerial surveys from 16 Jul through 9 Oct 2010.

Activities and Speeds— Specific activities were recorded for five beluga whale sightings. Four sightings were of traveling whales and one whale was resting. Whales classified as traveling or swimming moved at slow (two sightings) or moderate speeds (four sightings).

Headings—The headings of beluga whales were examined for animals considered to be swimming or traveling. Headings of seven beluga whales were recorded. These individuals had a mean vector heading of 90º with an angular standard deviation of 78° (p=0.35; Fig. 6.13).

Estimated Number of Belugas Present and Potentially Affected— Methods for calculating odontocete whale (beluga and unidentified odontocete whales) exposures to received sound levels ≥180 dB and ≥160 dB) were the same as those used for mysticete whales. We estimated that less than one odontocete was potentially exposed to sound levels ≥180 dB (1.3 exposures), and that 2 individuals were potentially exposed to sound levels ≥160dB (20.2 exposures each; Table 6.9) if they showed no avoidance to the survey activities.

TABLE 6.9. Estimated number of individual beluga whales exposed to received levels ≥180 and ≥160 dB during seismic survey activities by Shell in the Harrison Bay area and average number of exposures per individual during 16 Jul - 9 Oct 2010 in the Harrison Bay area.

Exposure level in dB re 1 uPa (rms)	Individuals Exposed	Exposures per Individual
≥ 180 dB	0.09	1.31
≥ 160 dB	2.14	20.20

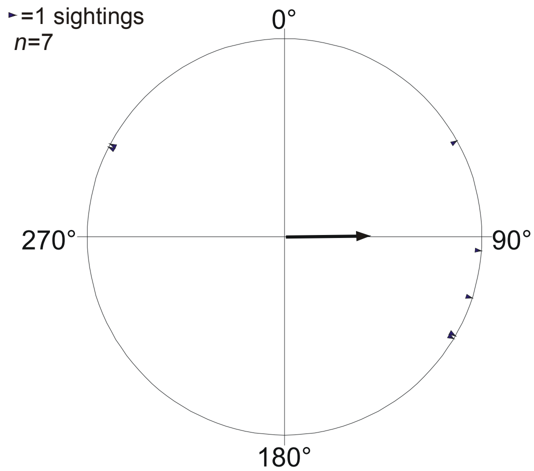

FIGURE 6.13. Headings of beluga whales in Harrison Bay from 16 Jul through 9 Oct 2010.

Polar bears

Twelve on-effort polar bears sightings (18 individuals) were recorded in the Harrison Bay area (Fig. 6.14). Two sightings were recorded during the pre–seismic period, one sighting was during seismic activities, four during post–seismic periods, and five during non–seismic periods. Three of the sightings were sows with cubs, and all other sightings were single animals (9) that were either adults or bears of undetermined age.

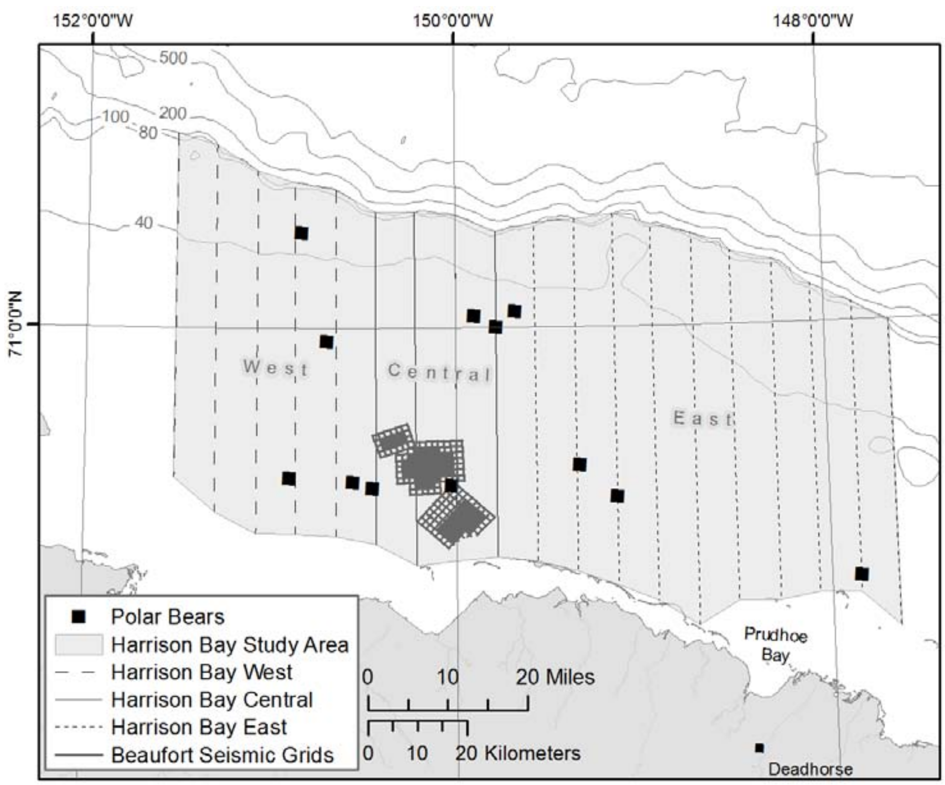

FIGURE 6.14. Polar bear sightings during aerial surveys relative to shallow hazard seismic activities in the Harrison Bay area during 16 Jul - 9 Oct 2010.

Seals

A total of 167 bearded seal sightings (171 individuals), 34 ringed seal sightings (79 individuals), 9 walrus sightings (10 individuals), 5 unidentified pinnipeds (8 individuals) and 425 sightings (676 individuals) of small, unidentified seals, was recorded during aerial surveys (Figs. 6.15 and 6.16). Seals were only visible during optimal sightability conditions and were not easily identifiable to species at the survey altitude of 305 m (1000 ft) above sea level; therefore, no in–depth analyses of seal data were conducted.

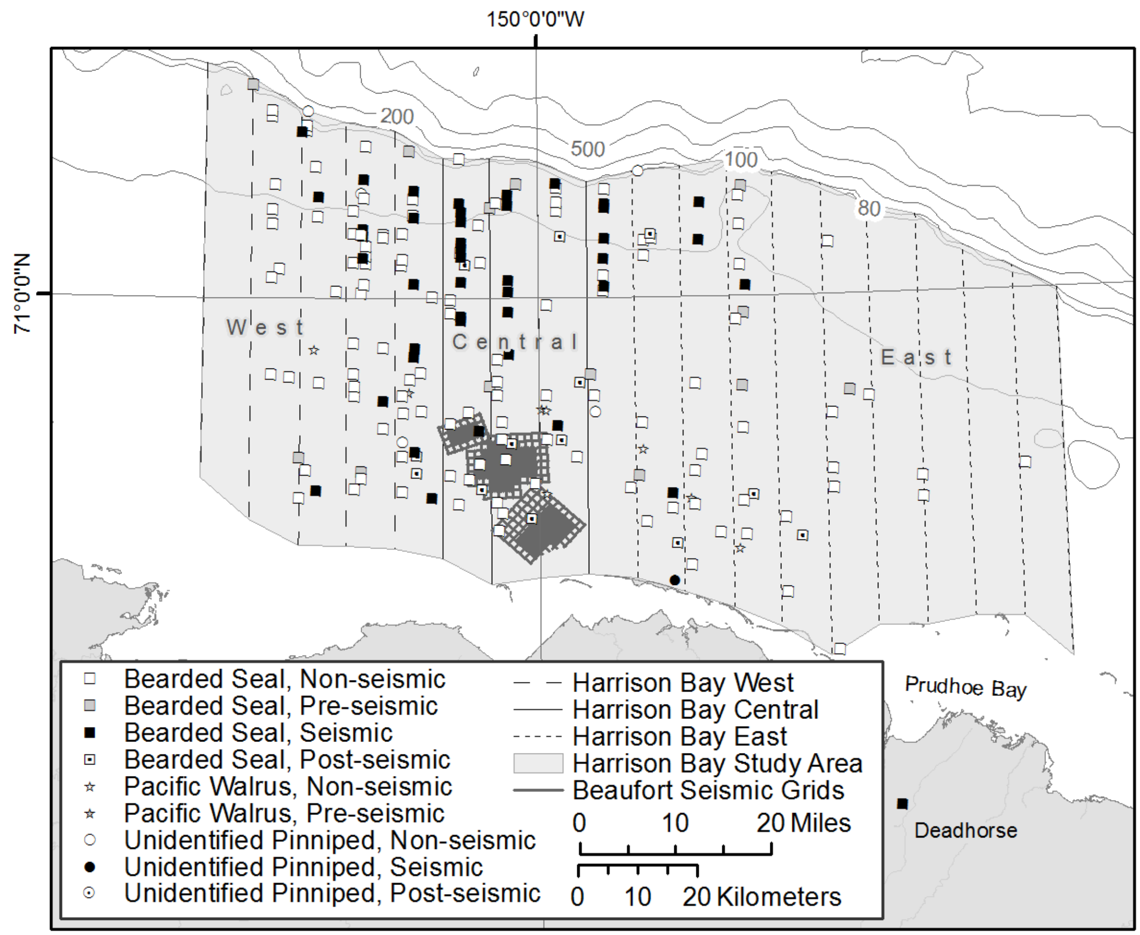

FIGURE 6.15. Bearded seal and unknown pinniped sightings during aerial surveys in the Harrison Bay area during 16 Jul - 9 Oct 2010.

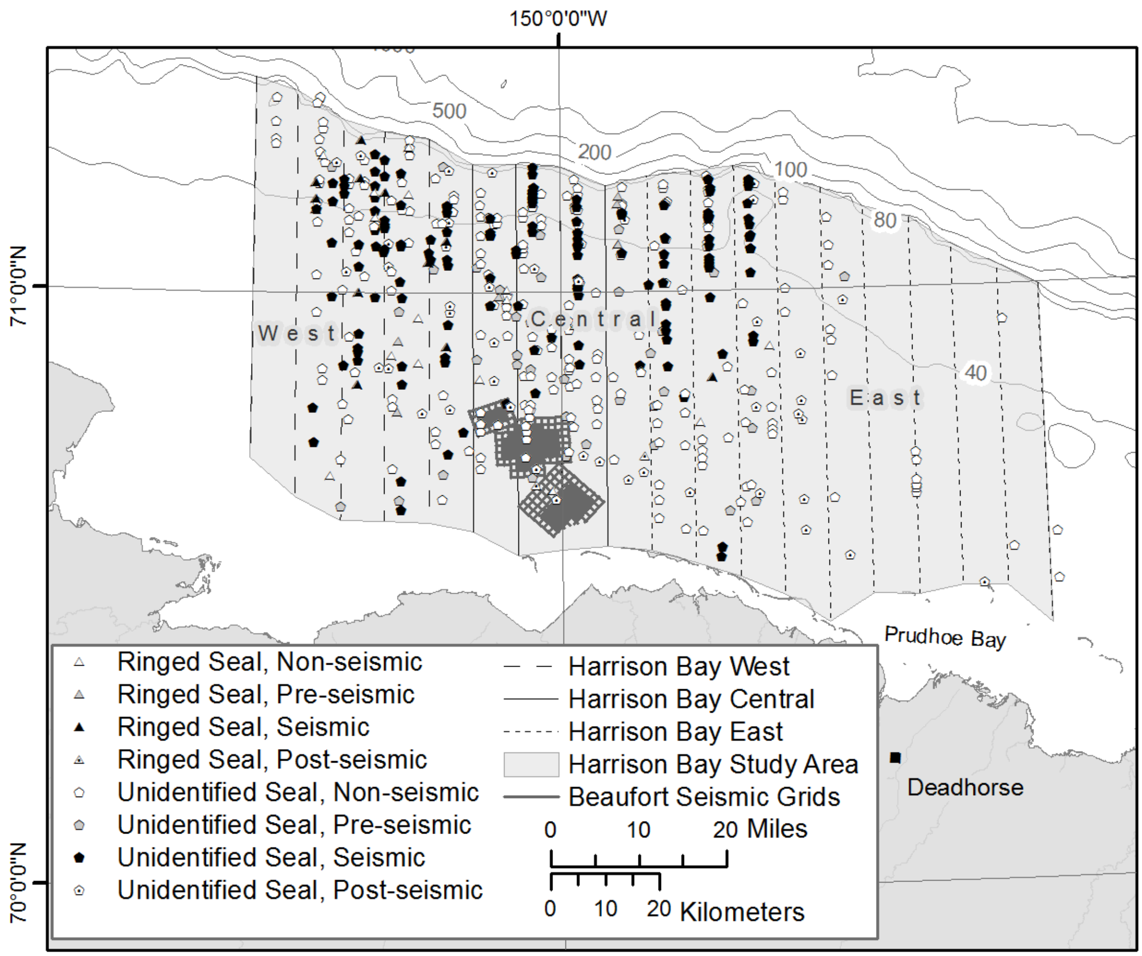

FIGURE 6.16. Ringed seal, spotted seal and unidentified seal sightings during aerial surveys in the Harrison Bay area during 16 Jul - 9 Oct 2010.

Camden Bay Area

<u>*Survey effort*</u>

Surveys were flown in Camden Bay from 22 Jul to 29 Aug for a total of 2776 km (1725 mi) of effort during 7 surveys (Fig. 6.17). Survey effort ranged from 242 km (150 mi) to 638 km (396 mi) per survey with poor weather, low ceiling or high winds frequently prohibiting or truncating survey effort.

When assessed by 5–km distance-from-shore bins, survey effort was highest in the 5–10 km (3–6 mi) from shore bin. In general, effort was relatively high to approximately 60 km (37 mi) offshore and dropped substantially beyond 70 km (43 mi) from shore (Fig. 6.218).

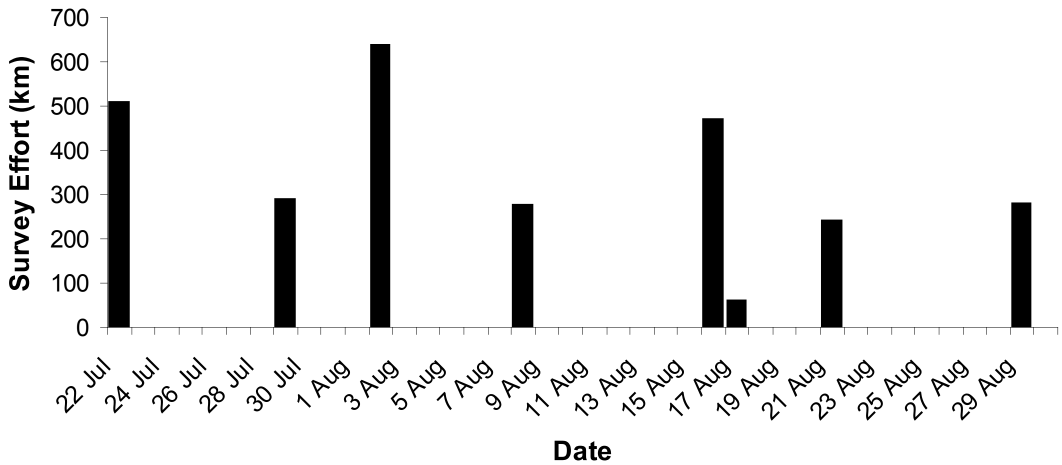

FIGURE 6.17. Survey effort in Camden Bay from 22 Jul to 29 Aug 2010.

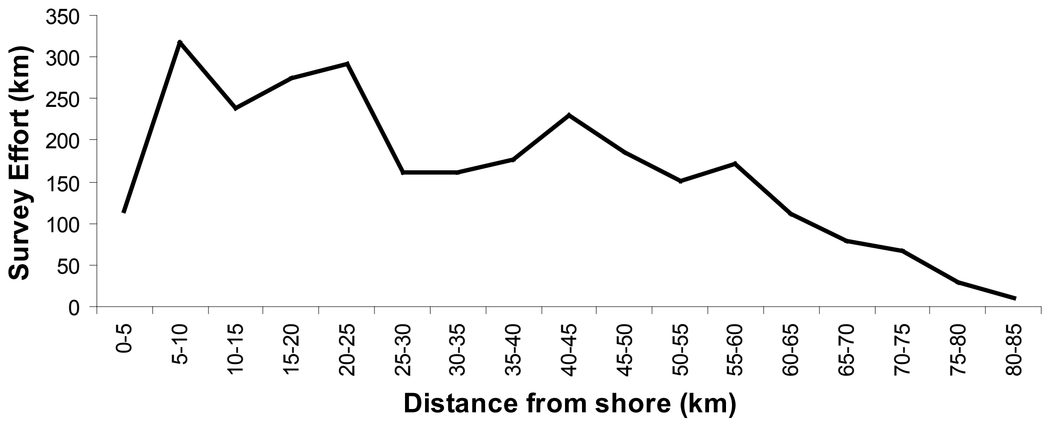

FIGURE 6.18. Aerial survey effort by 5–km (3.1 mi) distance-from-shore bins in Camden Bay from 22 Jul to 29 Aug 2010.

Bowhead Whales

Sightings and Sighting Rates.—A total of 25 bowhead whale sightings (31 individual whales) were recorded during Jul–Aug surveys in Camden Bay. Fifteen of these sightings (17 individuals) were recorded on–transect in acceptable sightability conditions (Table 6.10, Fig. 6.19; see *Methods* for definitions of sightability and on–transect) and are used in the following analyses and discussion. Bowhead whales were observed on 43% of surveys at an average rate of 6 sighting/1000 km. We observed 0–15 individuals per survey, with corresponding sighting rates from 0–46 sightings/1000 km (0–74 sightings/1000 mi) and 0 to 53 individuals/1000 km (0–86 individuals/1000 mi). Bowhead whale sighting rates were highest in late Aug, with a peak rate of 46 sightings/1000 km (74 sightings/1000 mi) on 29 Aug.

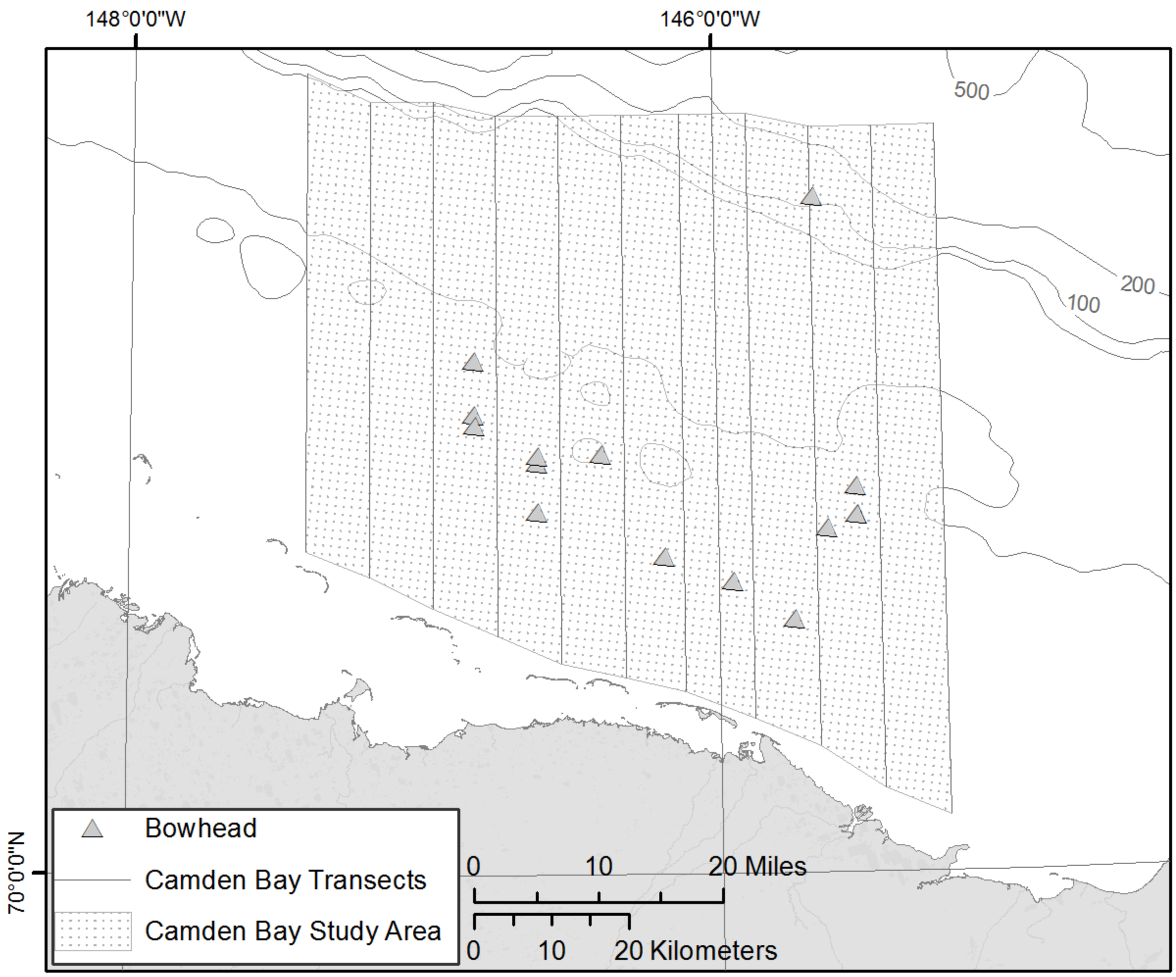

FIGURE 6.19. Bowhead whale sighting locations during Jul–Aug surveys in Camden from 22 Jul to 29 Aug 2010.

TABLE 6.10. Summary of aerial survey effort and sighting rates in Camden Bay from 22 Jul to 29 Aug 2010. Numbers of sightings and individuals in parentheses were based on <500 km of effort and should be viewed with caution. Sighting rates were not calculated ("NC") when effort was less than 250 km (155 mi).

Date	Survey No.	Effort (km)	Percent of Survey Area	Bowhead Whale			
				Sightings	Individuals	Sightings/ 1000 km	Individuals/ 1000 km
22 Jul	1	509	71	1	1	2.0	2.0
29 Jul	2	291	41	(0)	(0)	0.0	0.0
2 Aug	3	638	89	0	0	0.0	0.0
8 Aug	4	279	39	(0)	(0)	0.0	0.0
16-17 Aug	5	532	74	1	1	1.9	1.9
21 Aug	6	242	34	(0)	(0)	NC	NC
29 Aug	7	284	40	(13)	(15)	45.7	52.8
Total/Average	**7**	**2776**	**55***	**15**	**17**	**5.9***	**6.7***

* Average sighting rate

Distance from Shore and Depth**—**Bowhead whale sighting rates were greatest at locations ranging from 20–35 km (12–22 mi) offshore (Fig. 6.20) during the 2010 Camden Bay surveys. Another peak in sighting rates occurred 65-70 km (40-42 mi) offshore. The highest bowhead sighting rate occurred in the 30-35 km (19-22 mi) distance-from-shore bin.

Bowhead whales were sighted in water depths varying from 9 to 37 m (29 to 123 ft) during this survey period. Bowhead sighting rates were highest in locations where water depth ranged from 30–40 m (98–131 ft) (Fig. 6.21). A small peak in bowhead sighting rates occurred in shallower water 10 to 20 m (33-66 ft) in depth.

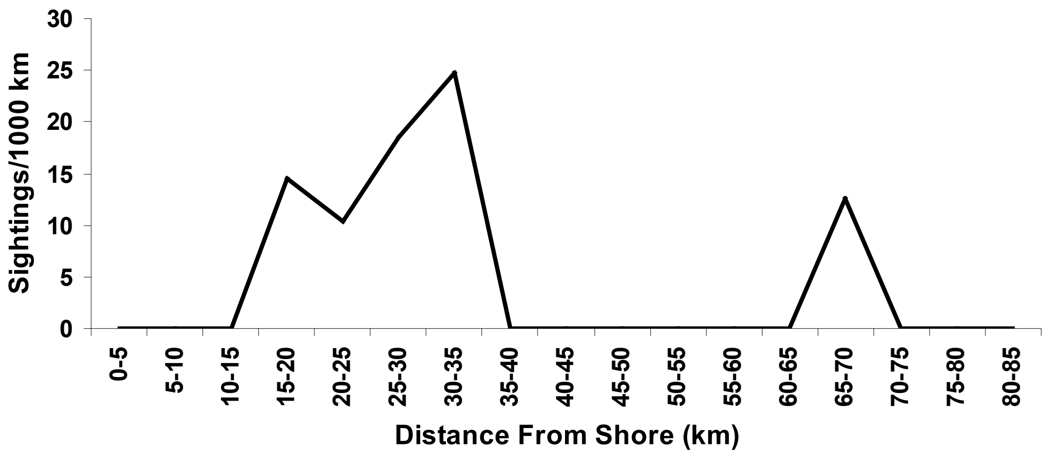

FIGURE 6.20. Bowhead sighting rates within 5–km distance-from-shore bins during aerial surveys from 22 Jul through 29 Aug 2010.

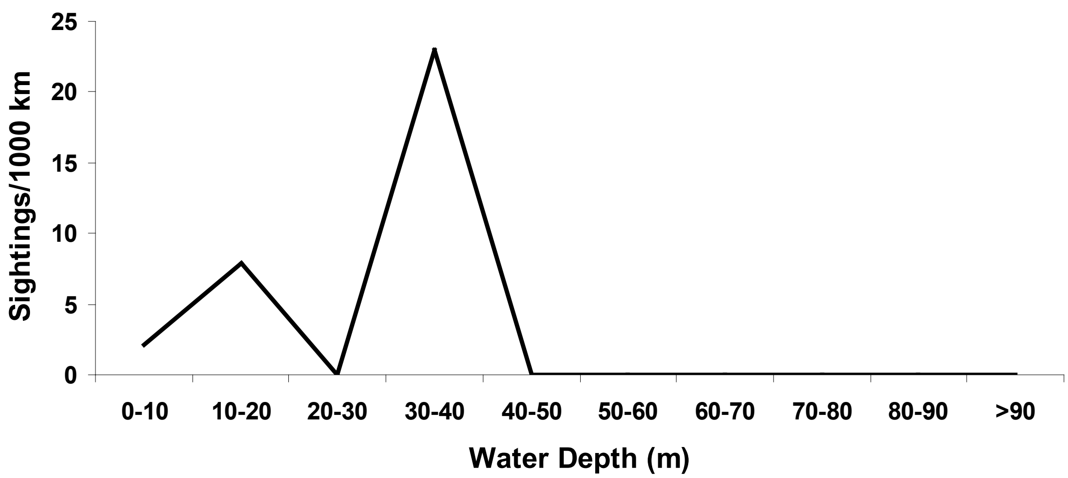

FIGURE 6.21. Number of bowhead whale sightings within 10–m water depth intervals during aerial surveys from 22 Jul through 29 Aug 2010.

***Activities*—**Specific activities were recorded for ten bowhead whale sightings. Eight sightings were of traveling whales, one was of a breaching whale, and one whale was resting (Fig. 6.22).

***Speed*—**Bowhead whales that were classified as traveling moved at slow (two sightings), moderate (four sightings) or fast speeds (two sightings; Fig. 6.23).

***Headings*—**The headings of migrating bowhead whales were examined for animals considered to be swimming or traveling. Headings of twelve bowhead whales were recorded, eleven on the 29 Aug, and one on the 22 Jul. These individuals had a mean vector heading of 302.3ºT with an angular standard deviation of 52°T (p <0.001; Fig. 6.24). A mean vector heading in a westerly direction was expected during the fall migration, indicating that these animals were likely early fall migrants. .

FIGURE 6.22. Observed activities of bowhead whales sighted during aerial surveys from 22 Jul through 29 Aug 2010 in Camden Bay.

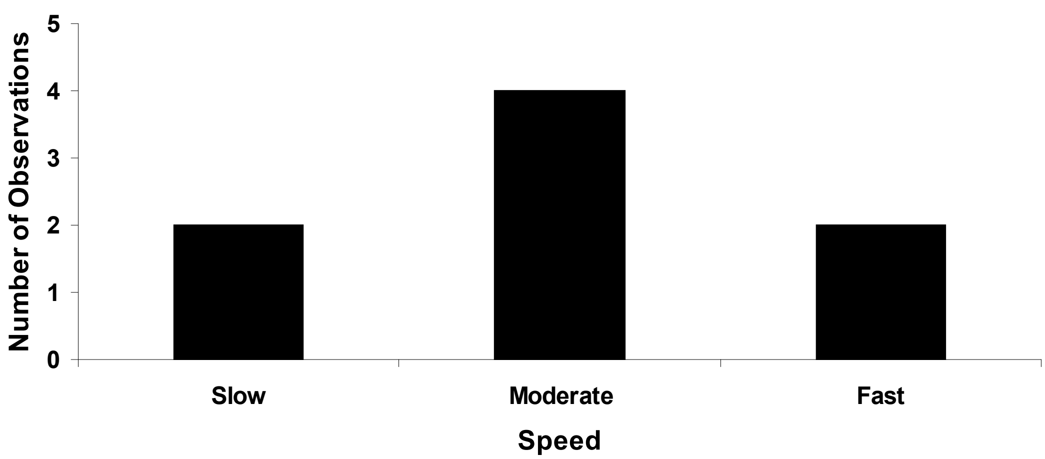

FIGURE 6.23. Observed speed of traveling bowhead whales sighted during aerial surveys from 22 Jul through 29 Aug 2010 in Camden Bay.

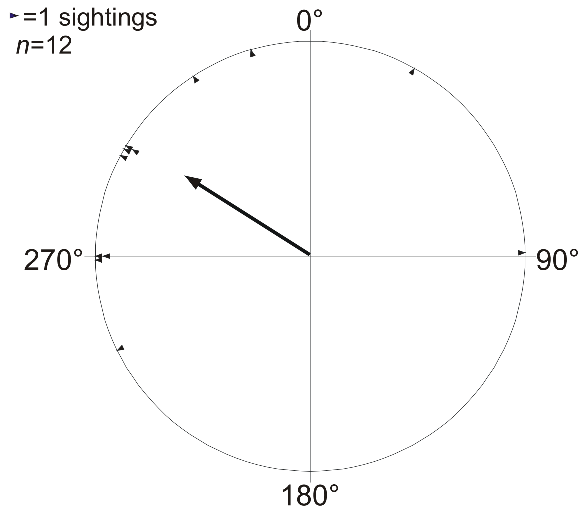

FIGURE 6.24. Headings of bowhead whales in Camden Bay from 22 Jul through 29 Aug 2010.

Beluga Whales

Sighting Rates—A total of 8 beluga whale sightings (10 individuals) were recorded from 22 Jul to 29 Aug in Camden Bay (Table 6.11). Sighting rates during individual surveys were relatively low (0–14 sightings/1000 km), reflecting the patchy distribution of belugas within the study area (Fig. 6.25). The highest number of belugas (8 individuals) was detected on 22 Jul.

TABLE 6.11. Summary of aerial survey effort and beluga whale sighting rates in Camden Bay from 22 Jul through 29 Aug 2010. Numbers of sightings and individuals in parentheses were based on <500 km (311 mi) of effort and should be viewed with caution. Sighting rates were not calculated (“NC”) when effort was less than 250 km (155 mi).

Date	Survey No.	Effort (km)	Percent of Survey Area	Beluga Whale			
				Sightings	Individuals	Sightings/ 1000 km	Individuals/ 1000 km
22 Jul	1	509	71	7	8	13.7	15.7
29 Jul	2	291	41	(1)	(2)	3.4	6.9
2 Aug	3	638	89	0	0	0.0	0.0
8 Aug	4	279	39	(0)	(0)	0.0	0.0
16-17 Aug	5	532	74	0	0	0.0	0.0
21 Aug	6	242	34	(0)	(0)	NC	NC
29 Aug	7	284	40	(0)	(0)	0.0	0.0
Total/Average	**7**	**2776**	**55***	**8**	**10**	**3.2***	**4.0***

* Average sighting rate

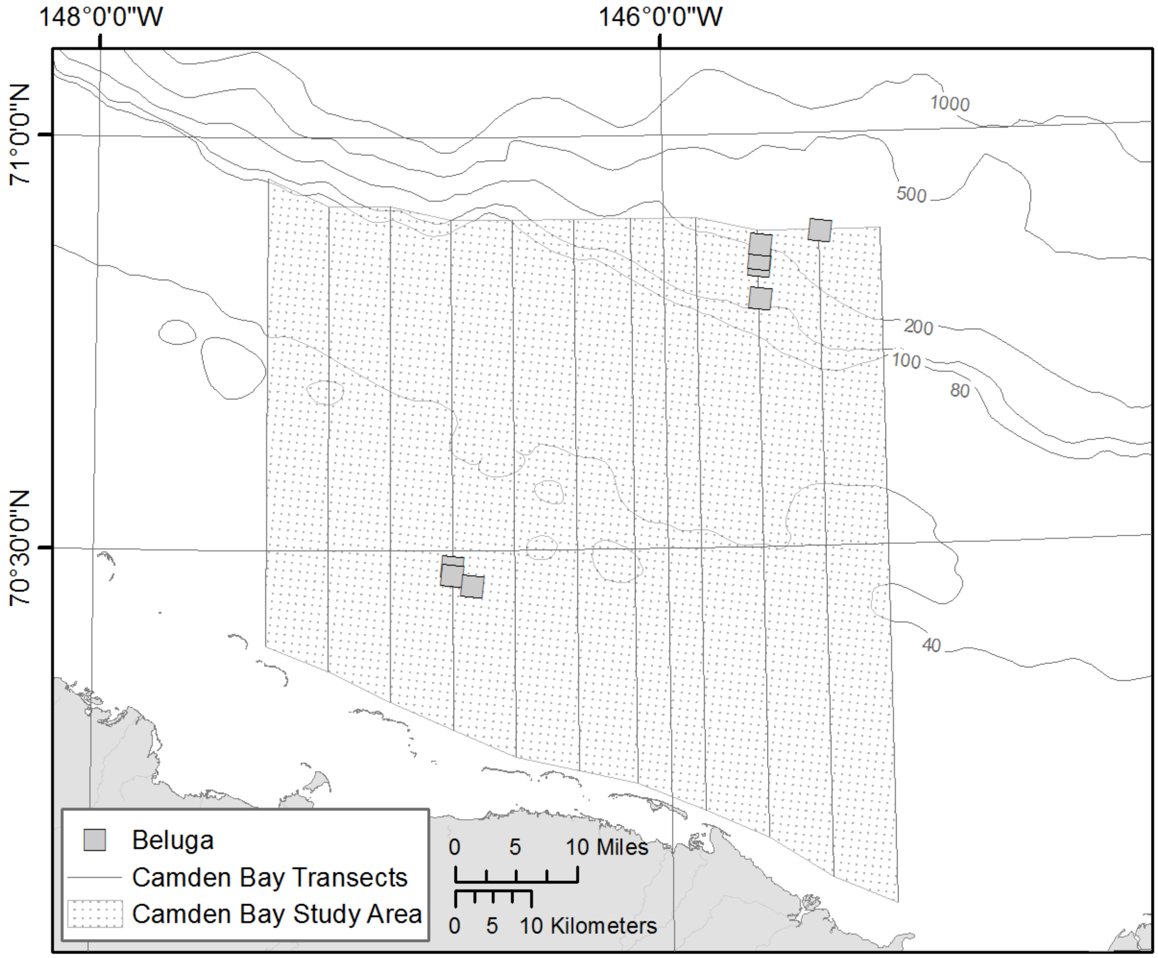

FIGURE 6.25. Beluga whale sightings during aerial surveys in Camden Bay 22 Jul through 29 Aug, 2010.

Distance from Shore and Depth—Beluga whale sightings increased in frequency at the northern end of transects, and most sightings were between 65 and 80 km (40 and 50 mi) from shore (Fig. 6.26). A smaller peak in beluga sighting rates occurred 20-25 km offshore. Most beluga sightings were on the northern portions of the survey area, at depths > 40 m (131 ft).

Activities and Speed— Specific activities were recorded for five beluga whale sightings all of which were of traveling whales. Based on beluga observations for which movement data were collected, all beluga whales were moving at slow speeds (100%) while swimming or traveling.

Headings—The headings of beluga whales were examined for animals considered to be swimming or traveling. Headings of eight beluga whales were recorded. These individuals had a mean vector heading of 84ºT with an angular standard deviation of 44°T (p = 0.01; Fig. 6.27).

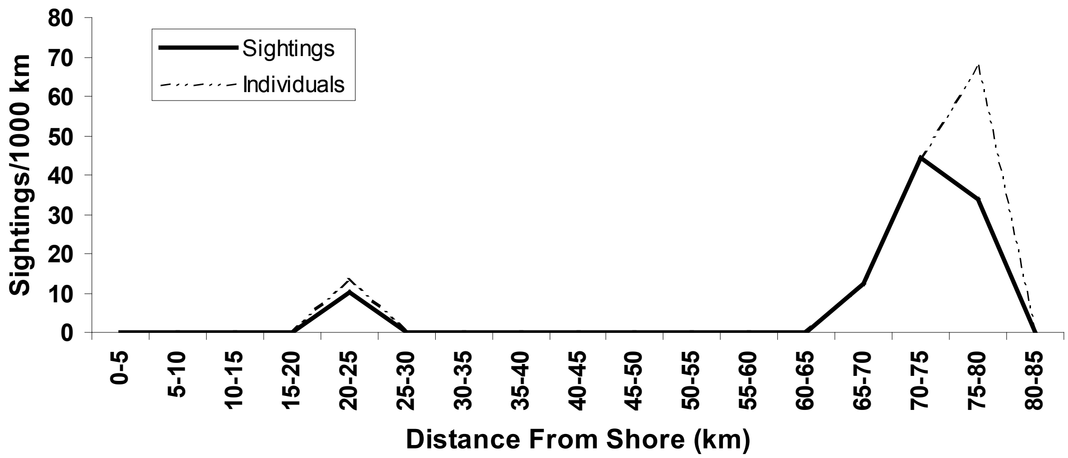

FIGURE 6.26. Beluga whale sighting rates by distance from shore during aerial surveys in Camden Bay from 22 Jul through 29 Aug 2010. Number of sightings/1000 km and number of individuals/1000 km are shown.

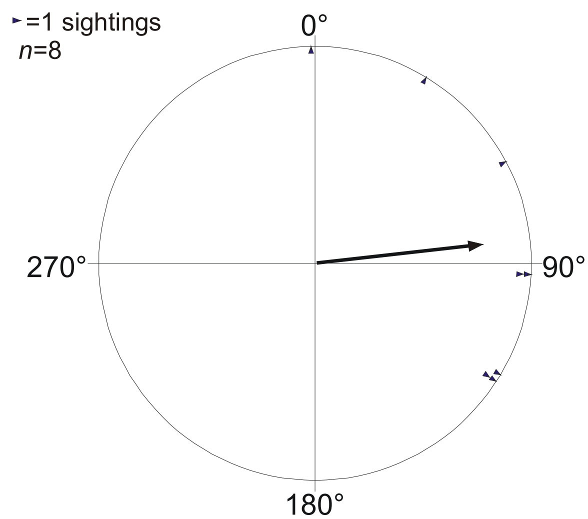

FIGURE 6.27. Headings of beluga whales in Camden Bay from 22 Jul through 29 Aug 2010.

Polar bears

One polar bear was sighted in Camden Bay on the 17 Aug. The bear was sighted approximately 20 km north of the barrier islands and was walking on an ice floe.

Seals

A total of 27 bearded seal sightings (44 individuals), 1 ringed seal sightings (40 individuals), two unidentified pinniped sightings (two individuals) and 91 sightings (496 individuals) of small, unidentified seals, was recorded during the 2010 Camden Bay aerial surveys (Figs. 6.28 and 6.29). Seals were only visible during optimal sightability conditions and were not easily identifiable to species at 305 (1000 ft) above sea level; therefore, no in–depth analyses of seal data were conducted.

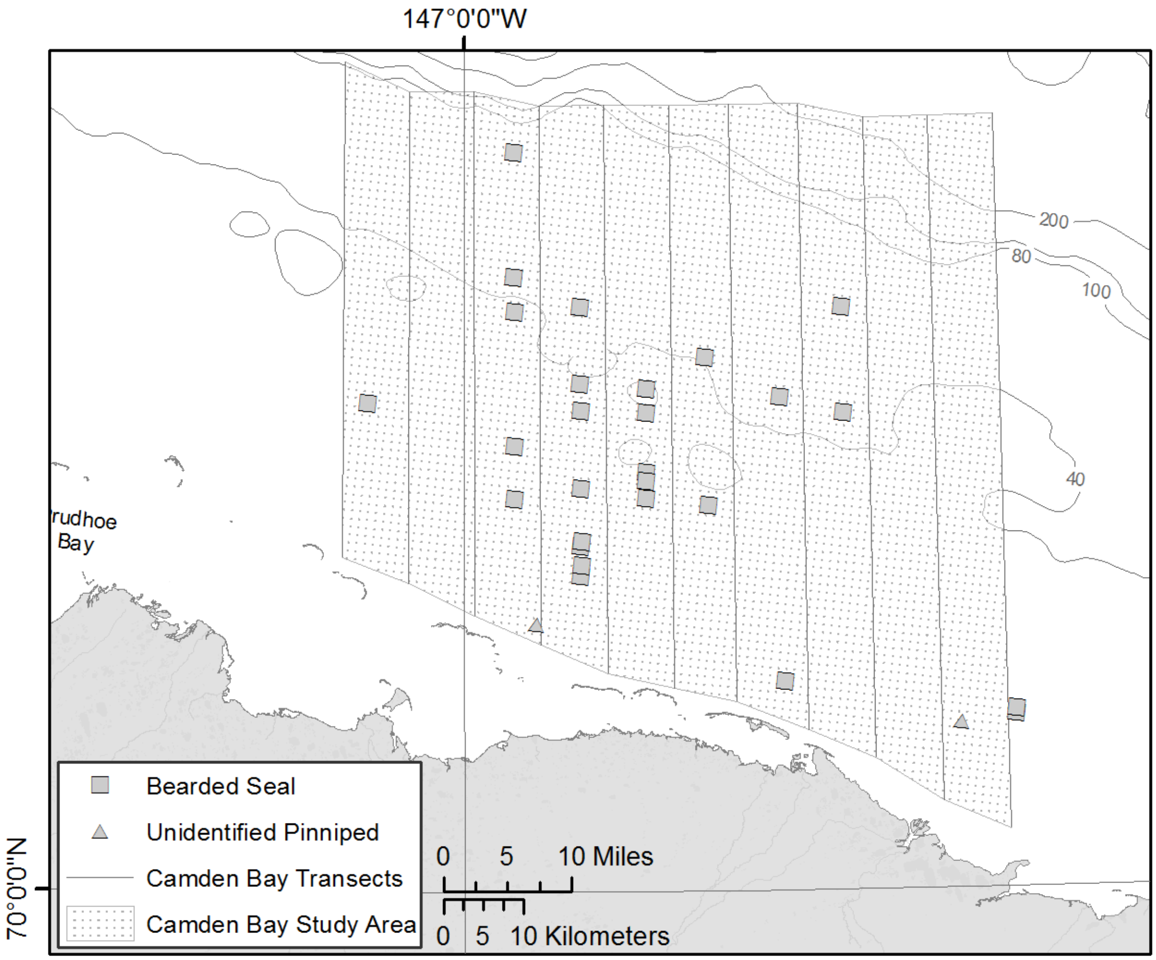

FIGURE 6.28. Bearded seal and unidentified pinniped sightings during aerial surveys in Camden Bay from 22 Jul through 29 Aug 2010.

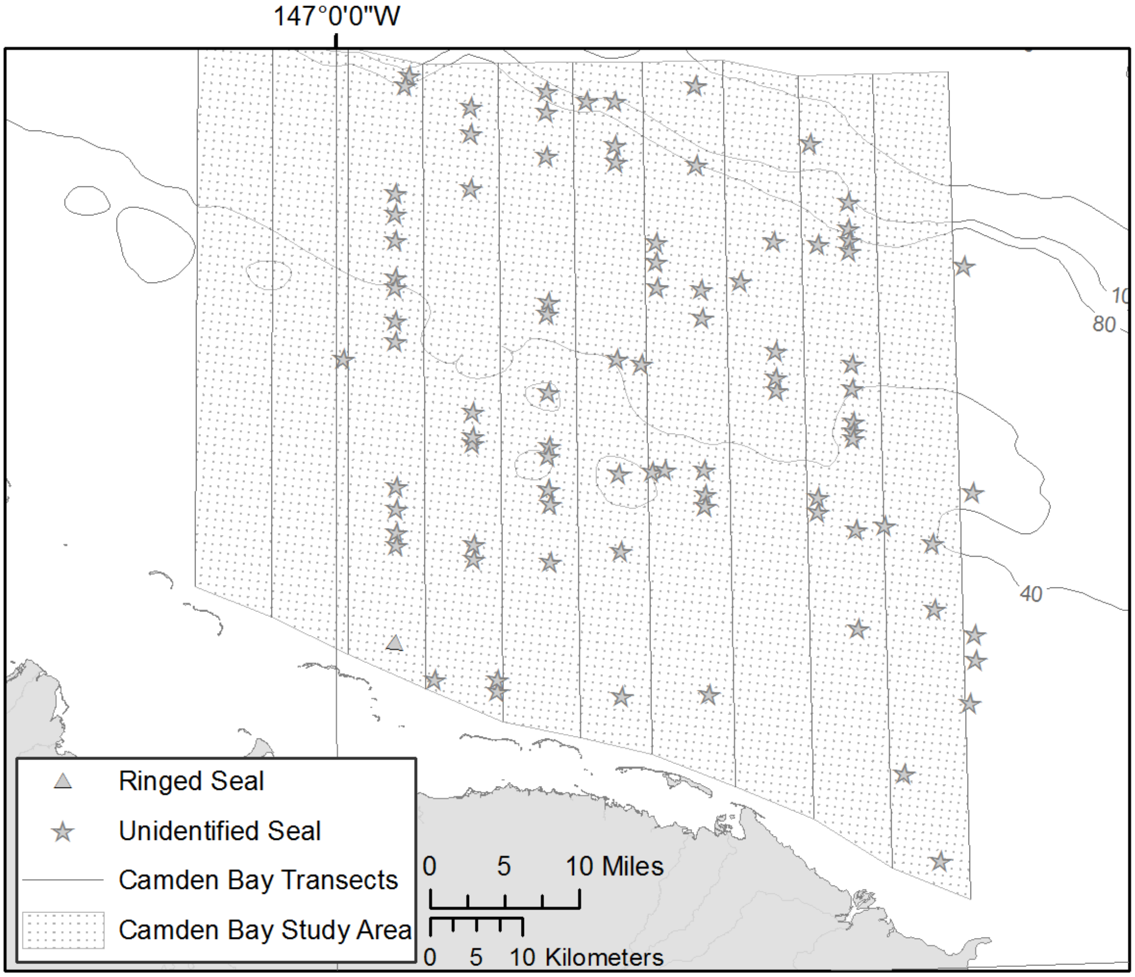

FIGURE 6.29. Ringed seal and unidentified seal sightings during aerial surveys in Camden Bay from 22 Jul through 29 Aug 2010.

Discussion

Observations of bowheads during Shell's 2010 aerial survey program in the Beaufort Sea were consistent with the general pattern of bowhead whale fall migration from the Beaufort Sea to overwintering areas in the Bering Sea. Peak sighting rates occurred in late Aug (29 Aug) within Camden Bay and a few days later (8 Sep) in Harrison Bay. Whales in both areas were mostly observed heading west, which would be expected from fall migrants. Bowhead whales in Harrison Bay were observed predominately traveling while moving in a slow to moderate speed and tended to be dispersed between 15-70 km (9-43 mi) from shore with a peak sighting rate at 60-65 km (37-40 mi) offshore, in waters around 10 m (33 ft) deep. In contrast, sightings made during Jul–Aug surveys of Camden Bay indicated that whales were closer inshore (15–35 km; 9-22 mi) in waters around 35 m (115 ft) deep.

The difference between Camden Bay and Harrison Bay in the distribution of bowhead sighting distances relative to shore may be a direct result of the pattern of ice conditions in the Beaufort (and especially in Harrison Bay) during the study period (Fig. 6.30). This hypothesis is discussed in more detail below.

Overall trends in beluga activity, speed, distance from shore, and sighting rates were consistent with previously observed trends (Miller et al. 2002, Würsig et al. 2002). Beluga sighting rates were highest in early Jul and the majority of migrating belugas appeared to pass north of our survey area, with peak sighting rates near the shelf break. Beluga activities consisted primarily of traveling at slow to moderate speeds. These data are consistent with prior research indicating that belugas spend the majority of their time in the Beaufort Sea along the shelf break or far offshore during spring and fall migrations (Treacy 1994; Richard et al. 1997, 1998).

Polar bear distribution was more dispersed than previous years in the Harrison Bay area (Fig. 6.16), and this was most likely related to the persistent presence of ice. In past years (2007 and 2008) most of the polar bear sightings were on the barrier islands, but this year all sightings were recorded on ice or in water (Christie et al. 2010).

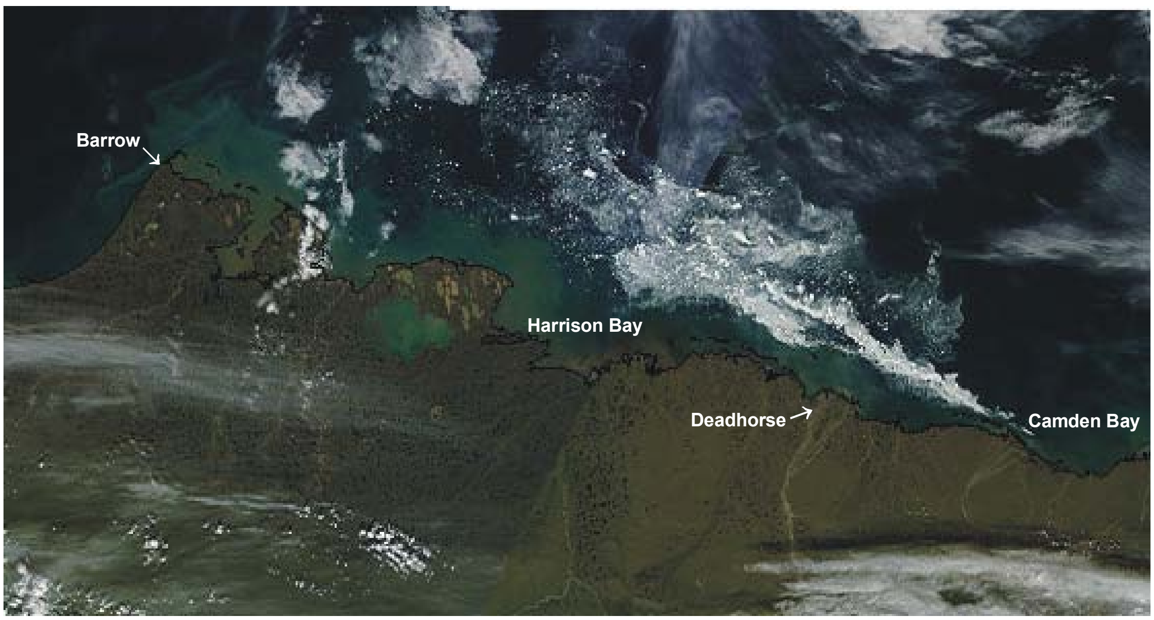

FIGURE 6.30. Satellite image of the Arctic 14 Aug, 2010. The Harrison Bay survey area lies on the eastern half of that Bay and extends about as far north as the edge of the ice in that area. The extent of the ice in Harrison Bay is evident, as well as differences in the distribution of ice between Harrison and Camden Bay survey areas. Image from the Moderate Resolution Imaging Spectroradiometer (MODIS) website: http://rapidfire.sci.gsfc.nasa.gov/subsets/index.php?subset=AERONET_Barrow.

Interpreting patterns of bowhead distribution and behavior around the seismic activity in the Harrison Bay area in 2010 was challenging for several reasons. First, the persistent ice made it difficult for the seismic ship (*Mt. Mitchell*) to maneuver on the prospects, and seismic activity was limited for much of the season (Appendix Fig. K.1). Likewise, the presence of ice indirectly limited aerial survey effort (although to a much lesser extent) because it contributed to a persistent atmospheric inversion, and a related marine layer of fog. Towards the end of the season, much of the ice shifted out of the study area, and seismic activity was more consistent. One resulting outcome of these environmental conditions was that the first bowhead sighting during seismic activity did not occur until 1 Oct (eight days before the end of the survey season), and all of the bowhead sightings during seismic activity were recorded during one week at the start of October (Table 6.1).

The distribution of sightings suggests that bowheads were closer to the seismic survey area during seismic activity than during non-seismic periods (Fig. 6.5; Table 6.5). This is somewhat counter-intuitive. Differences in ice conditions during the last week of the survey season (when all of the sightings of bowheads during seismic activity were recorded) may have resulted in a shift in bowhead distribution at the end of the season, coincident with the last two peaks of seismic activity (Appendix Fig. K.1). Until the end of the fall season, bowheads may have been farther from shore and associated with the northern edge of the ice near more open water, which was roughly adjacent to the northern edge of the survey area during most of Sep. In fact, all bowhead sightings up until mid-Sep were on the northern half of the transect lines. When the ice shifted out of the study area in early October, the distribution of whales may have shifted closer to shore (and hence closer to the seismic survey area). A second plausible explanation for this pattern is that the distribution of sightings is only an apparent shift in distribution. That is, it may be easier to detect bowheads in open water compared to even moderate sea-ice. This could be due to a combination of factors ultimately resulting in a difference in detectable sighting cues (e.g. all else being equal, the surface wake of a swimming animal is likely to have a larger footprint in open water). These analyses are preliminary, and we acknowledge (and stress) that interpretations of the observed patterns should be made with caution until the data are analyzed in a more comprehensive frame-work.

While the effect of seismic activity on bowhead distribution in the study area is confounded by the nature and timing of sightings, seismic activity and ice conditions -- the number of bowheads exposed to underwater sound from seismic survey activities in 2010 appears to have been small. The estimate of 27 whales exposed to ≥160 dB in the Harrison Bay area represents a fraction equal to 0.0019 of the estimated population size in 2001 (Zeh and Punt 2005). Further, the population is known to have been growing exponentially during the 1980s and 1990s (Brandon and Wade 2006), and if that trend has continued during the last decade, the fraction of the population exposed to seismic in 2010 would be even smaller.

Taking into account the various factors which inevitably affect the detection and distribution of bowheads will allow us to provide more robust estimates of exposure of marine mammals to underwater sound from exploratory activities. However, because the number of exposures is largely a function of the limited seismic survey effort and relatively small ensonified area in 2010, it seems unlikely that the small magnitude of those exposure estimates will change dramatically in future analyses.

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7. CHUKCHI SEA VESSEL-BASED MARINE MAMMAL MONITORING RESULTS[1]

Monitoring Effort and Marine Mammal Encounter Results

This section summarizes the visual observer effort and marine mammal sightings from the *Mt. Mitchell, Ocean Pioneer,* and *Arctic Seal* during Shell's 2010 marine surveys in the Alaskan Chukchi Sea. The survey period began when the *Mt. Mitchell* entered the Chukchi Sea study area on 31 July 2010 (AKDT) and ended when the *Mt. Mitchell* and *Ocean Pioneer* departed the Chukchi Sea study area on 16 Oct 2010. The *Arctic Seal and Ocean Pioneer* entered the Chukchi Sea study area on 1 and 3 Aug 2010, respectively. The *Arctic Seal* departed the Chukchi Sea study area on 3 Oct 2010. All three vessels departed the Chukchi Sea study area at times during the survey period for crew changes or re-supply activities, or to conduct survey operations in the Beaufort Sea.

Collectively, the three vessels traveled along a total of 13,372 km (8309 mi) of trackline in the Chukchi Sea study area. The *Ocean Pioneer, Mt. Mitchell,* and *Arctic Seal* traveled along 5958 km (3702 mi), 4670 km (2902 mi), and 2744 km (1705 mi) of trackline, respectively. There were no airgun operations conducted by Shell in the Chukchi Sea in 2010. The *Ocean Pioneer* conducted the majority of the marine survey activities in the Chukchi Sea with an emphasis on ice-gouge surveys using high-frequency (e.g., >180 kHz), low-energy sound sources. Most of the *Mt. Mitchell* activity in the Chukchi Sea study area occurred during transit periods to and from Harrison Bay in the Beaufort Sea, which is where the most of its 2010 survey operations occurred. The *Arctic Seal* assisted with crew changes and was often in port or at anchor for extended periods.

Other Vessels

Project vessels did not routinely operate within 5 km (3.1 mi) of other vessels during survey operations. Proximity to other vessels may have influenced the number and behavior of marine mammals sighted from project vessels; however, the extent of this potential influence was unlikely to have been significant. Vessels not participating in the project transited well away from survey activities, and MMOs observed no instances of harassment or disturbance to marine mammals due to the presence of other vessels.

Observer Effort

MMOs on the three vessels were on watch for a total of 8191 km (5089 mi; 667 hr). The following sections present this effort by seasonal period, daylight versus darkness, Beaufort wind force (Bf), and the number of MMOs on watch.

<u>*Effort by Seasonal Period*</u>

Observer effort was distributed evenly between the Jul–Aug and Sep–Oct seasonal periods with ~50% of the total survey effort occurring in each period (Fig. 7.1). The survey vessels entered the project area in late Jul and most observer effort during the Jul–Aug seasonal period occurred in Aug. Increasing periods of darkness during the Sep–Oct seasonal period reduced the amount of time per day available for observers to be on watch compared to the Jul–Aug period. Many of the monitoring results presented in the following sections were divided into these two seasonal periods given the biological significance of seasonality and differences in environmental conditions between these periods.

[1] By C. M. Reiser, D. M. Savarese, and J. Beland

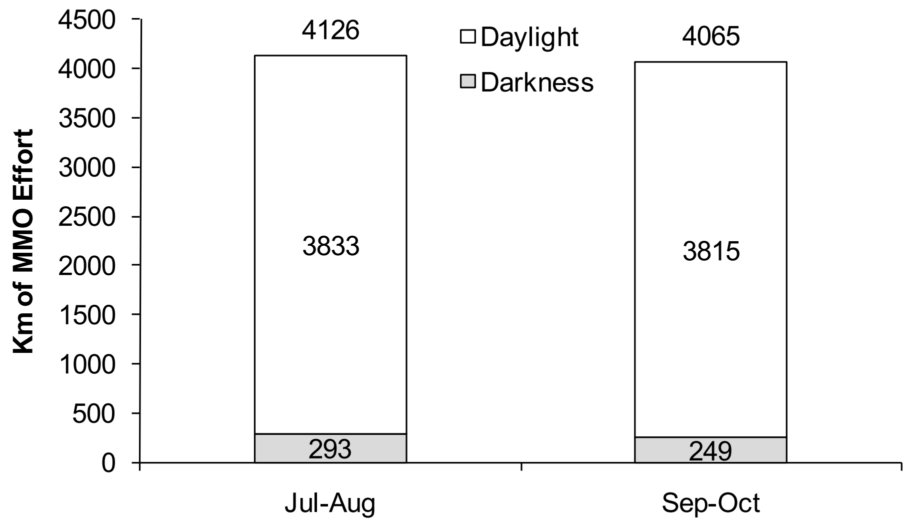

FIGURE 7.1. Marine mammal observer effort (km) by seasonal period and daylight status during Chukchi Sea marine surveys, 31 Jul–16 Oct 2010.

Effort by Beaufort Wind Force

Trends in sea conditions were similar during the Jul–Aug and Sep–Oct seasonal periods when MMOs were on watch (Fig. 7.2). The percentage of observer effort was higher during Jul–Aug (55%) than Sep–Oct (42%) during periods of Bf 4–6. However, the percentage of observer effort in the two seasonal periods was equal when considering periods of Bf 3–6. Approximately 80% of the survey effort occurred when Bf conditions ranged from 3-6 during both seasonal periods.

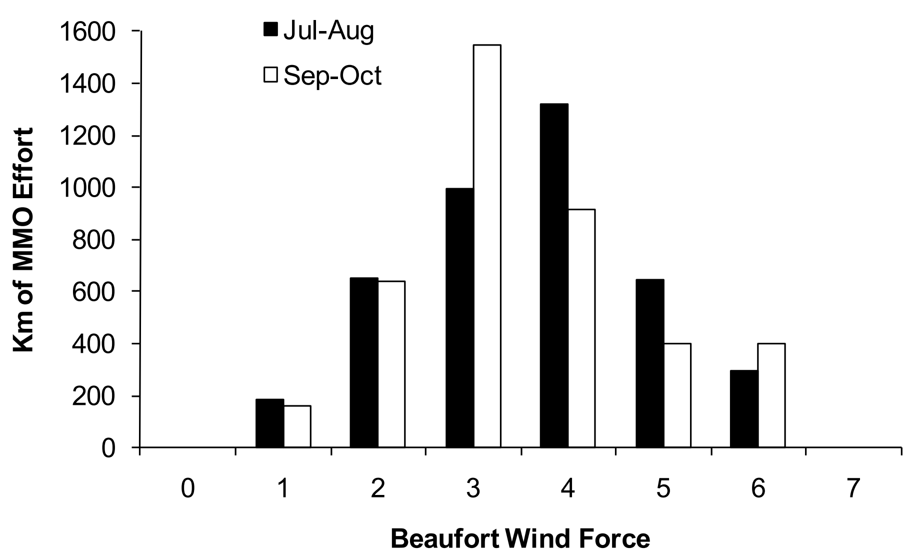

FIGURE 7.2. Marine mammal observer effort (km) by Beaufort wind force and seasonal period during Chukchi Sea marine surveys, 31 Jul–16 Oct 2010.

<u>*Effort by number of MMOs*</u>

Combined visual observation effort with two MMOs on watch was approximately twice that of observation effort with only one MMO on watch (Fig. 7.3). The difference in survey effort as a function of number of MMOs on watch was greater in Jul–Aug than Sep–Oct. The predominance of two-observer effort was a result of the *Mt. Mitchell* and *Ocean Pioneer* being staffed with five MMOs throughout the majority of the survey. Increasing darkness in Sep–Oct allowed observers to maximize periods when at least two MMOs were on watch, resulting in approximately 66% of observation effort occurring with at least two MMOs on watch during this period. There was only one MMO aboard the *Arctic Seal*, and over 41% of the one-MMO watch effort was from the *Arctic Seal*.

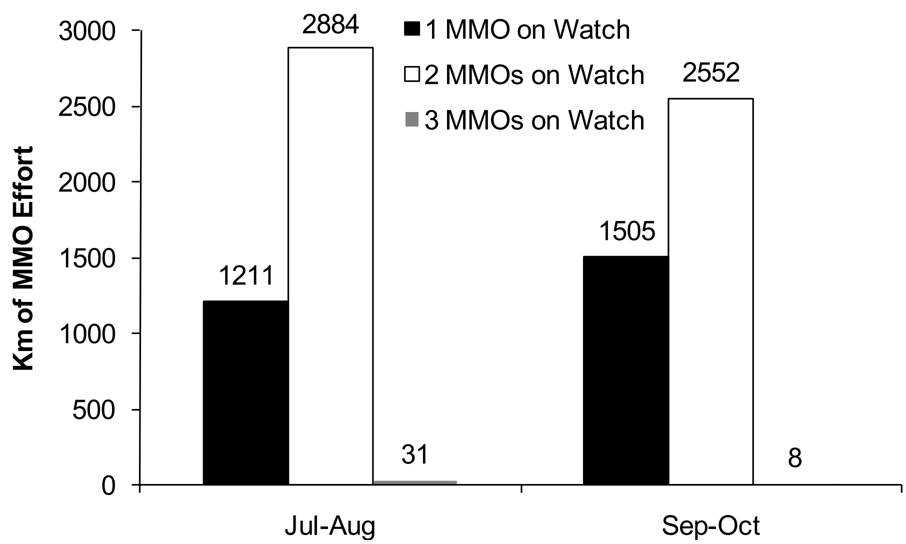

FIGURE 7.3. Marine mammal observer effort (km) by number of MMOs on watch and seasonal period during Chukchi Sea marine surveys, 31 Jul–16 Oct 2010.

Marine Mammal Sightings

MMOs recorded a total of 187 groups of marine mammals (318 individuals) during Chukchi Sea survey operations in 2010. These totals included one dead ringed seal (*Phoca hispida*), which was not included in analyses of data. The seal carcass was observed by MMOs aboard the *Ocean Pioneer* on 3 Sep and was in an advanced state of decomposition. See Appendix Table L.6 and Appendix Figures L.1–L.12 for a detailed list of all marine mammal detections and weekly sighting summary maps. The most commonly observed group of marine mammals was seals which accounted for 79 s ightings (86 individuals). The most commonly identified seal species was bearded seal (*Erignathus barbatus*) which was recorded on 2 9 occasions (29 individuals). S ixty-four cetacean sightings (101 individuals) were recorded. Gray whale (*Eschrichtius robustus*) was the most commonly identified species (19 sightings of 28 individuals) followed by bowhead whale (*Balaena mysticetus*) with 14 sightings of 21 individuals. Forty-four Pacific walrus (*Odobenus rosmarus*) sightings (131 individuals) were recorded during the 2010 Chukchi Sea marine surveys. Polar bears (*Ursus maritimus*) were not observed during Shell's 2010 Chukchi Sea operations. The single ringed seal carcass was the only sighting of a dead marine mammal, and no injured marine mammals were encountered during the 2010 Chukchi Sea marine surveys. See Appendix L for a detailed summary of each marine mammal sighting during 2010 i n the Chukchi Sea study area, including weekly sighting maps.

Cetacean Sightings

Collectively, MMOs aboard the three vessels recorded 101 cetaceans in 64 groups during Chukchi Sea marine surveys (Table 7.1). The majority (~63%) of cetacean sightings were recorded during the Sep–Oct period. The most commonly identified cetacean species was gray whale (19 sightings of 28 individuals) followed by bowhead whale (14 sightings of 21 individuals). Gray whales were recorded in similar numbers during the Jul–Aug and Sep–Oct seasonal periods, however bowheads were recorded more frequently during the Sep–Oct period. Fewer sightings of harbor porpoise and Minke whale were recorded and one sighting of killer whale was reported. Approximately 34% of the cetaceans sighted could not be identified to species.

TABLE 7.1. Number of sightings (number of individuals) of cetaceans observed during Chukchi Sea marine surveys, 31 Jul–16 Oct 2010.

Species	Jul - Aug	Sep - Oct	*Total*
Cetaceans			
Bowhead Whale	1 (1)	13 (20)	***14 (21)***
Gray Whale	11 (13)	8 (15)	***19 (28)***
Harbor Porpoise	0	4 (10)	***4 (10)***
Killer Whale	0	1 (2)	***1 (2)***
Minke Whale	2 (3)	2 (2)	***4 (5)***
Unidentified Mysticete Whale	10 (13)	8 (14)	***18 (27)***
Unidentified Whale		4 (8)	***4 (8)***
Total Cetaceans	***24 (30)***	***40 (71)***	***64 (101)***

Cetacean Sighting Rates

Cetacean sighting rates were calculated using only the periods of effort that met the criteria for being able to reliably detect cetaceans (See Chapter 4 and Appendix E) and the sightings that occurred during those periods (Appendix Tables L.1 and L.2).

Cetacean Sighting Rates by Seasonal Period and Number of MMOs on Watch – Overall cetacean sighting rates in Sep–Oct were significantly higher than in Jul–Aug ($\chi^2 = 4.04$, $df = 1$, $p = 0.044$; Fig. 7.4). Cetacean sightings rates were higher when two MMOs were on watch than when only one MMO was on watch during both the Jul–Aug and Sep–Oct periods however, these differences were not significant ($\chi^2 = 0.19$, $df = 1$, $p = 0.664$ for Jul–Aug and $\chi^2 = 0.22$, $df = 1$, $p = 0.641$ for Sep–Oct).

Cetacean Sighting Rates by Beaufort Wind Force – No clear trend in cetacean sighting rates as a function of Beaufort wind force was evident (Fig. 7.5). Cetacean sighting rates were higher when sea conditions were Bf 2 and 5 compared to Bf 3 and 4. Most observer effort occurred during periods when the Bf was ≥2. The level of effort during the lower Beaufort winds forces (Bf = 0 and 1) was low (Fig. 7.2) and precluded meaningful comparison of cetacean sighting rates relative to Beaufort wind force for these categories.

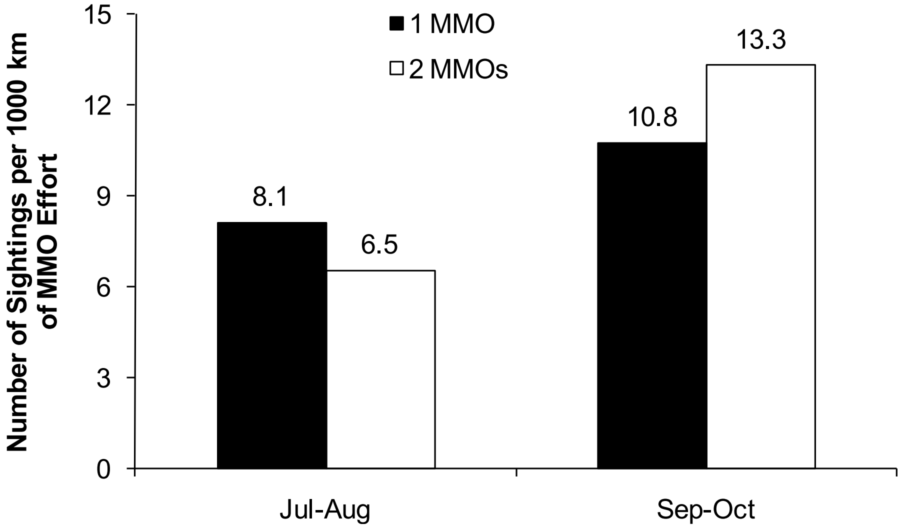

FIGURE 7.4. Cetacean sighting rates by number of MMOs on watch and seasonal period during Chukchi Sea marine surveys, 31 Jul–16 Oct 2010. Note that <250 km (155 mi) took place with 3 M MOs on watch, which precluded meaningful inclusion.

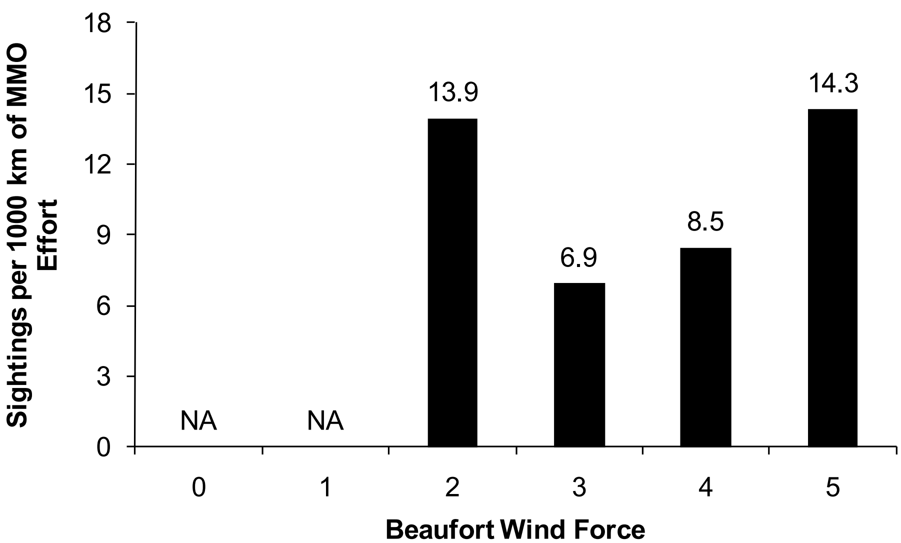

FIGURE 7.5. Cetacean sighting rates by Beaufort wind force during Chukchi Sea marine surveys, 31 Jul–16 Oct 2010. Note that <250 km (155 mi) took place in Bf 0 and 1, which precluded meaningful inclusion.

Seal Sightings

MMOs recorded 85 seals in 78 groups during the Chukchi Sea marine surveys in 2010 (Table 7.2). More bearded seal sightings and individuals were recorded than sightings and individuals of other species. More sightings and individuals were recorded for spotted seal compared to ringed seal. Approximately half of the seal sightings and individuals could not be identified to species.

TABLE 7.2. Number of sightings (number of individuals) of seals observed during Chukchi Sea marine surveys, 31 Jul–16 Oct 2010. All seals were in water.

Species	Jul - Aug	Sep - Oct	*Total*
Seals			
Bearded Seal	10 (10)	19 (19)	***29 (29)***
Ringed Seal	0	4 (4)	***4 (4)***
Spotted Seal	6 (12)	1 (1)	***7 (13)***
Unidentified Seal	9 (9)	23 (24)	***32 (33)***
Unidentified Pinniped	4 (4)	2 (2)	***6 (6)***
Total Seals	***29 (35)***	***49 (50)***	***78 (85)***

Seal Sighting Rates

Seal sighting rates were calculated using only the periods of effort that met the criteria for being able to reliably detect seals (See Chapter 4 and Appendix E) and the sightings that occurred during those periods (Appendix Tables L.3 and L.4).

Seal Sighting Rates by Seasonal Period and Number of MMOs on Watch – Seal sighting rates were higher with two MMOs on watch compared to periods with only one MMO on watch during both the Jul–Aug and Sep–Oct seasonal periods (Fig. 7.6), however these differences were not statistically significant ($\chi^2 = 0.22$, $df = 1$, $p = 0.638$ for Jul–Aug and $\chi^2 = 0.48$, $df = 1$, $p = 0.491$ for Sep–Oct). The difference in seal sighting rates with one and two MMOs on watch was also not significant when data from the two seasonal periods were pooled ($\chi^2 = 0.77$, $df = 1$, $p = 0.381$).

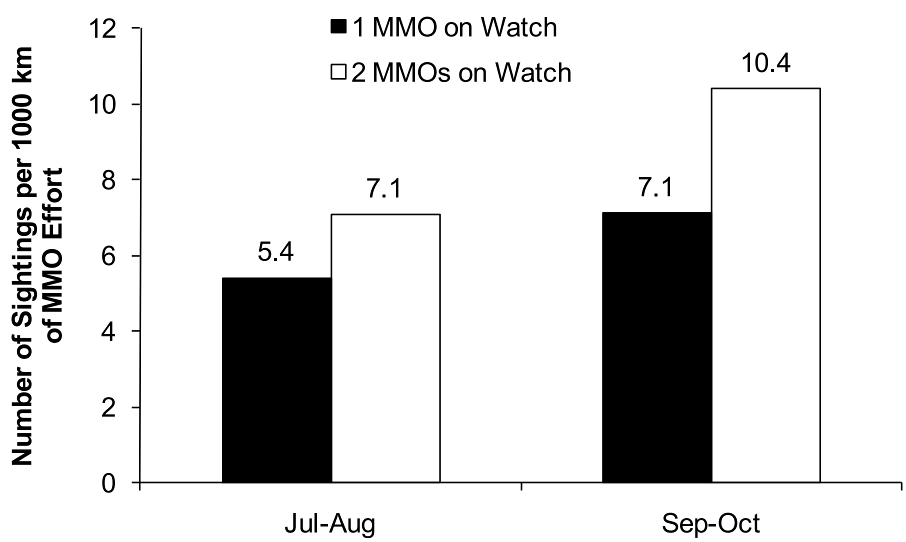

FIGURE 7.6. Seal sighting rates by number of MMOs on watch and seasonal period during Chukchi Sea marine surveys, 31 Jul–16 Oct 2010. Note that <250 km (155 mi) took place with 3 MMOs on watch, which precluded meaningful inclusion.

Seal Sighting Rates by Beaufort Wind Force– Observer effort when sea conditions were calm was low and precluded analysis of seal sighting rates as a function of Beaufort wind force when sea conditions were Bf 0 and 1 (Fig. 7.7). Seal sighting rates were highest when sea conditions were Bf 2 when compared to higher sea conditions. Seal sighting rates were similar when sea conditions ranged from Bf 3 to 5.

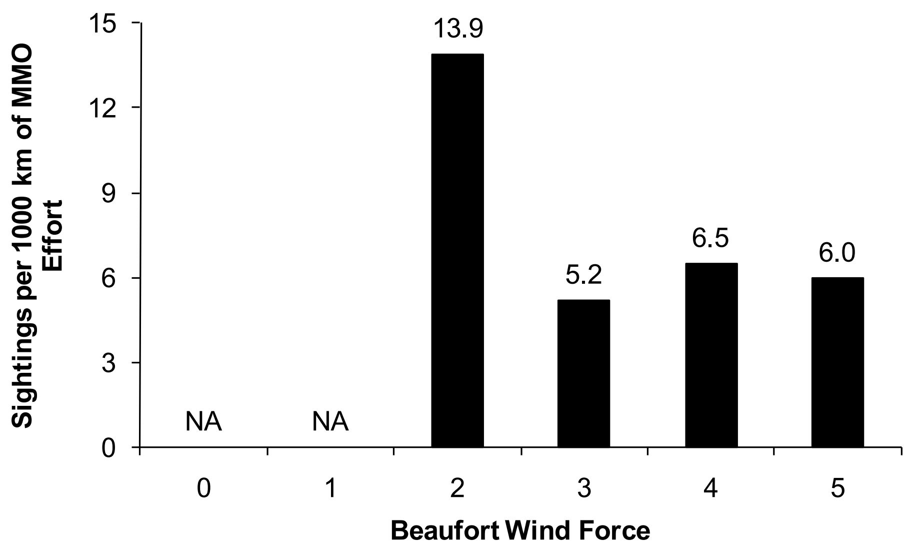

FIGURE 7.7. Seal sighting rates by Beaufort wind force during Chukchi Sea marine surveys, 31 Jul–16 Oct 2010. Note that <250 km (155 mi) took place in Bf 0 and 1, which precluded meaningful inclusion.

Pacific Walrus Sightings

MMOs recorded 44 sightings of 131 individual Pacific walruses during the Chukchi Sea marine surveys in 2010 (Table 7.3). Most sightings and individuals were recorded in Jul–Aug with fewer sightings and individuals in Sep–Oct.

TABLE 7.3. Number of sightings (number of individuals) of seals observed during Chukchi Sea marine surveys, 31 Jul–16 Oct 2010. All walruses were in water.

Species	Jul - Aug	Sep - Oct	*Total*
Pacific Walruses	***35 (119)***	***9 (12)***	***44 (131)***

Pacific Walrus Sighting Rates

Pacific walrus sighting rates were calculated using only the periods of effort that met the criteria for being able to reliably detect pinnipeds (See Chapter 4 and Appendix E) and the sightings that occurred during those periods (Appendix Tables L.3 and L.5).

Pacific Walrus Sighting Rates by Seasonal Period and Number of MMOs on Watch – No Pacific walrus sightings were recorded when only one MMO was on watch during the Chukchi Sea marine surveys in 2010 (Fig. 7.8). The higher walrus sighting rates with two MMOs on watch during Jul–Aug and Sep–Oct were not significantly different than sighting rates with only one MMO on watch (χ^2 = 3.633, *df* = 1, *p* = 0.057 for Jul–Aug and χ^2 = 1.298, *df* = 1, *p* = 0.254 for Sep–Oct). The level of effort with only one MMO on watch was marginal and these results should be viewed with caution. When data from both seasonal periods were combined however, walrus sighting rates were significantly higher with two MMOs on watch than with only one MMO (χ^2 = 4.740, *df* = 1, *p* = 0.029).

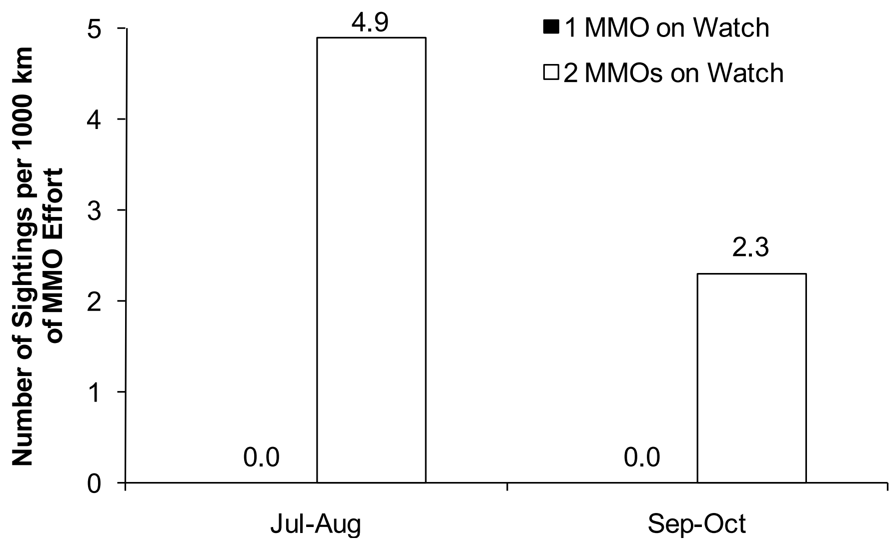

FIGURE 7.8. Pacific walrus sighting rates by number of MMOs on watch and seasonal period during Chukchi Sea marine surveys, 31 Jul–16 Oct 2010. Note that <250 km (155 mi) took place with 3 MMOs on watch, which precluded meaningful inclusion.

Pacific Walrus Sighting Rates by Beaufort Wind Force – Observer effort when sea conditions were calm was low and precluded analysis of walrus sighting rates as a function of Beaufort wind force when sea conditions were Bf 0 and 1 (Fig. 7.9). Walrus sighting rates were similar when sea conditions were Bf 2 and 3 and were reduced at higher sea conditions.

Polar Bear Sightings

No polar bear sightings were recorded during the Chukchi Sea marine surveys in 2010.

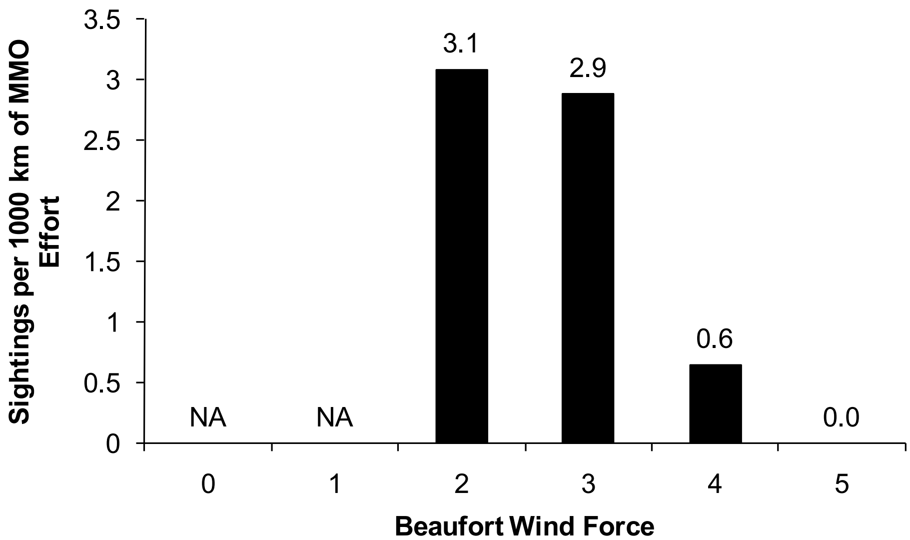

FIGURE 7.9. Pacific walrus sighting rates by Beaufort wind force during Chukchi Sea marine surveys, 31 Jul–16 Oct 2010. Note that <250 km (155 mi) took place in Bf 0 and 1, which precluded meaningful inclusion.

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Distribution and Behavior of Marine Mammals

Marine mammal behaviors and reactions were difficult to observe because individuals and/or groups of animals typically spent most of their time below the water surface and could not be observed for extended periods. Additionally, the MMOs primary duty was to implement mitigation rather than collect extensive behavioral data. The data collected during visual observations provided limited information about behavioral responses of marine mammals to the 2010 Chukchi Sea marine surveys. The relevant data collected by MMOs included estimated closest observed points of approach (CPA), direction of movement relative to the vessel, and behavior and reaction of animals at the time of the initial detections. No seismic survey activity occurred in the Chukchi Sea during Shell's marine surveys in 2010 so no comparisons of marine mammal behavioral categories during seismic and non-seismic periods could be made.

Cetaceans

Cetacean Closest Observed Point of Approach

The mean closest point of approach (CPA) of cetaceans was calculated using only sightings that occurred during periods of effort that met the criteria for being able to reliably detect cetaceans (See Chapter 4 and Appendix E). The mean cetacean CPA to the observer station during Shell's 2010 Chukchi Sea marine surveys was 1133 m (1239 yd; range 20 to 4000 m [22 to 4374 yd]; $n = 47$).

Cetacean Movement

Approximately 69% of cetacean movement relative to vessels was either "neutral" or "unknown" (Fig. 7.10). "Neutral" movement indicated that the animal(s) were neither swimming towards nor away from the vessel (e.g., swim parallel). Cetaceans swimming away from vessels was recorded more frequently that cetaceans swimming towards vessels.

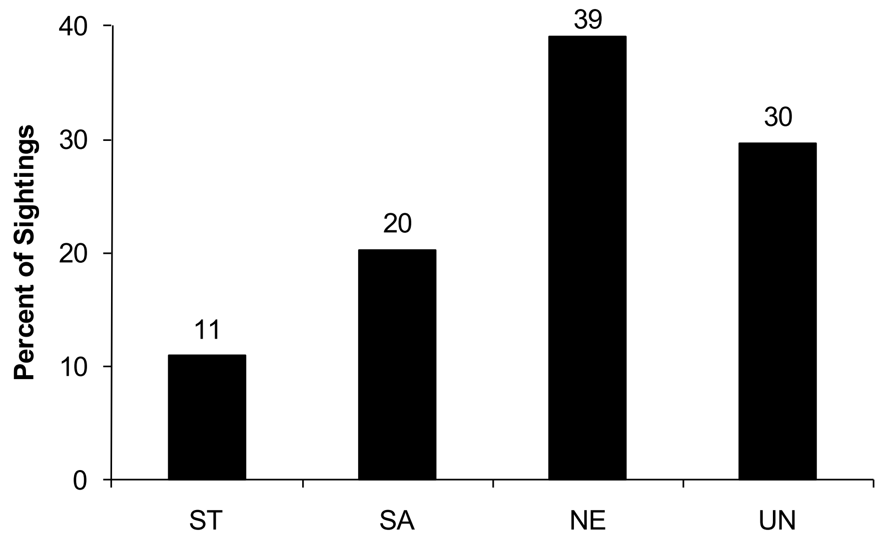

FIGURE 7.10. Cetacean movement with respect to vessels during Chukchi Sea marine surveys, 31 Jul–16 Oct 2010 (*n* = 64). Movement codes: ST = Swim Towards, SA = Swim Away, NE = Neutral, UN = Unknown

Cetacean Initial Behavior

The distances at which most cetaceans were initially detected from vessels made it more difficult to observe specific behaviors of cetaceans compared to pinnipeds. "Blow" was the most frequently recorded initial behavior for cetacean sightings (45% of sightings) followed by swimming (27% of sightings) during the 2010 Chukchi Sea marine surveys (Fig. 7.11). Other initial behaviors were recorded much less frequently.

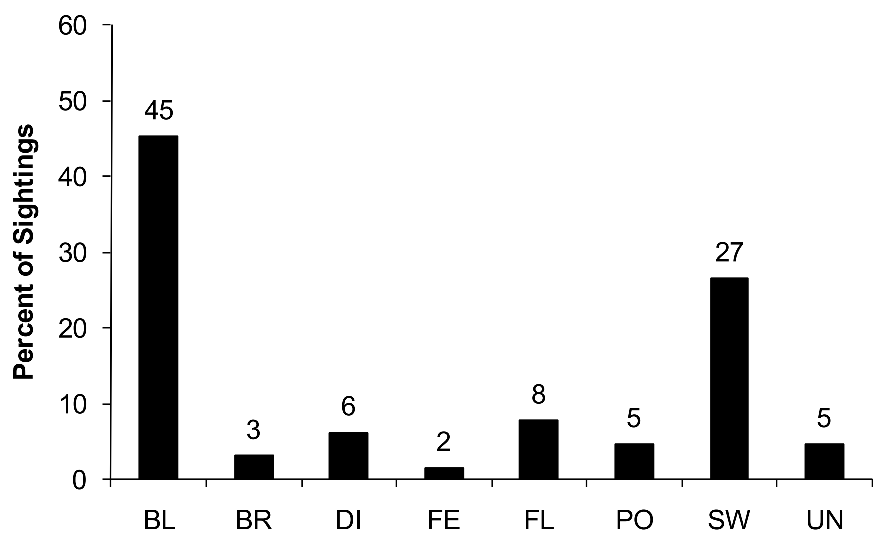

FIGURE 7.11. Cetacean initial behavior by seismic state during Chukchi Sea marine surveys, 31 Jul–16 Oct 2010 (*n* = 64). Behavior codes: BL = Blow, BR = Breach, DI = Dive, FE = Feed, FL = Fluke, PO = Porpoise, SW = Swim, UN = Unknown

Cetacean Reaction Behavior

MMOs looked for reactions to the vessel that included, "increase speed," "decrease speed," "change direction," "splash," etc. The large distances at which most cetaceans were observed made any potential reaction to the vessel difficult to distinguish. "No reaction" was recorded for most cetacean sightings (~97%) during the 2010 Chukchi Sea marine surveys. "Change direction" was recorded as the reaction behavior for two cetacean sightings. No other cetacean reaction behavior to vessels was observed.

Seals

Seal Closest Observed Point of Approach

The mean closest point of approach of seals to the observer station was calculated using only the sightings that occurred during periods of effort that met the criteria for being able to detect seals (See Chapter 4 and Appendix E). The mean seal CPA to the observer station during Shell's 2010 Chukchi Sea marine surveys was 300 m (328 yd; range 20–1479 m [22 to 1617 yd]; *n* = 42).

Seal Movement

Approximately 68% of seal movement relative to vessels was either "neutral" or "unknown" (Fig. 7.12). "Neutral" movement indicated that the animal(s) were neither swimming towards nor away from the vessel (e.g., swim parallel). Seals were recorded swimming towards slightly more often than swimming away from vessels.

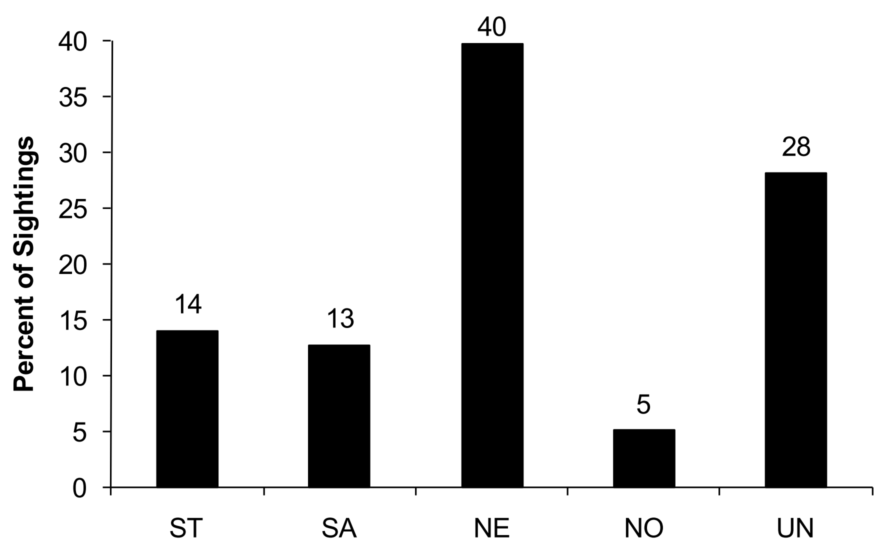

FIGURE 7.12. Seal movement relative to the vessel by seismic state during Chukchi Sea marine surveys, 31 Jul–16 Oct 2010. All seal sightings were in water, *n* = 78. Movement codes: ST = Swim Towards, SA = Swim Away, NE = Neutral, NO = None, UN = Unknown

Seal Initial Behavior

"Swim" and "look" were the most frequently recorded initial seal behaviors during the 2010 Chukchi Sea marine surveys comprising 82% of the recorded behaviors (Fig. 7.13). "Dive" was the next most frequently recorded behavior followed by "bow ride" and "swim away."

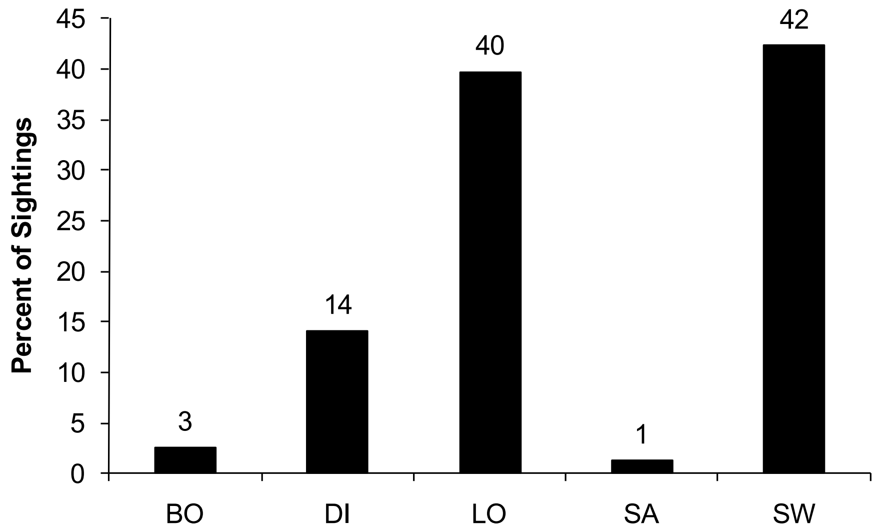

FIGURE 7.13. Seal initial behavior by seismic state during Chukchi Sea marine surveys, 31 Jul–16 Oct 2010. All seal sightings were in water, *n* = 78. Behavior codes: BO = Bow ride, DI = Dive, LO = Look (but not specifically at vessel), SA = Surface active, SW = Swim

Seal Reaction Behavior

Most seals (~68%) displayed no reaction to survey vessels during the 2010 Chukchi Sea marine surveys (Fig. 7.14). The remaining seal reaction behaviors recorded were "look" at the vessel and "increase speed."

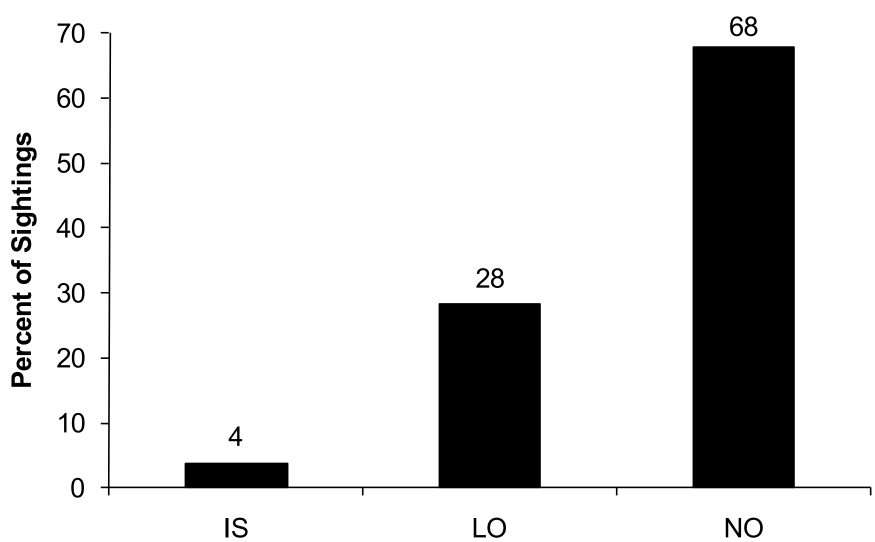

FIGURE 7.14. Seal reaction behavior during Chukchi Sea marine surveys, 31 Jul–16 Oct 2010. All seal sightings were in water, *n* = 78. Reaction behavior codes: IS = Increase Speed, LO = Look at Vessel, NO = No Reaction

Pacific Walruses

<u>*Pacific Walrus Closest Observed Point of Approach*</u>

The mean closest point of approach of Pacific walruses was calculated using only sightings that occurred during periods of effort that met the criteria for being able to detect Pacific walruses (See Chapter 4 and Appendix E). The mean walrus CPA to the observer station during Shell's 2010 Chukchi Sea marine surveys was 887 m (970 yd; range 80–2411 m[87 to 2637 yd]; *n* = 27).

<u>*Pacific Walrus Movement*</u>

Most walrus movement relative to vessels was recorded as either "neutral" or "unknown" (Fig. 7.15). Swim away was recorded for 25% of the sightings. "Neutral" movement indicated that the animal(s) were neither swimming towards nor away from the vessel (e.g., swim parallel). "Swim away" from the vessel was recorded more frequently than "swim towards."

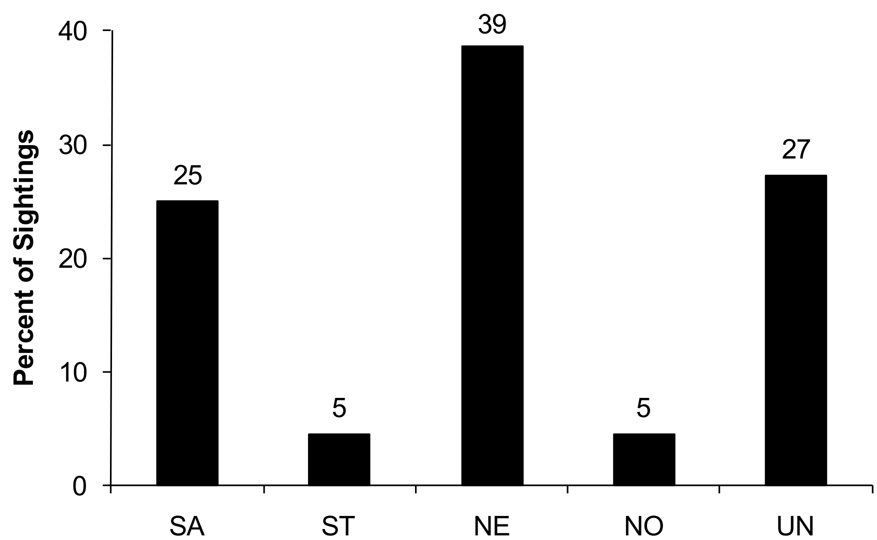

FIGURE 7.15. Pacific walrus movement relative to the vessel during Chukchi Sea marine surveys, 31 Jul–16 Oct 2010. All walrus sightings were in water, *n* = 44. Movement codes: SA = Swim Away, ST = Swim Toward, NE = Neutral, NO = None, UN = Unknown

<u>*Pacific Walrus Initial Behavior*</u>

"Swim" was the initial behavior recorded for most walrus sightings during the 2010 Chukchi Sea marine surveys (Fig. 7.16). Other initial behaviors were recorded less frequently.

<u>*Pacific Walrus Reaction Behavior*</u>

"No reaction" was recorded for most walrus sightings (~93%) during the 2010 Chukchi Sea marine surveys. "Look" at the vessel was recorded as the reaction behavior for three of the 27 walrus sightings. No other reaction behavior to vessels was observed for walruses.

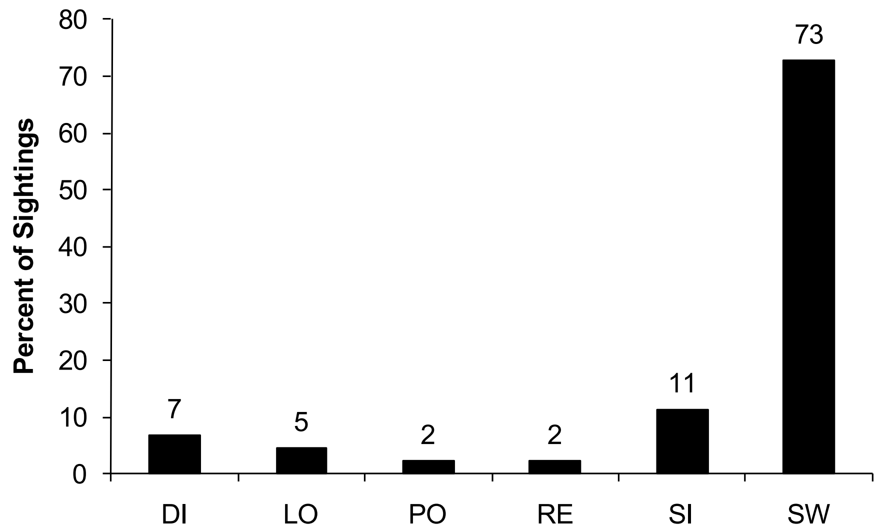

FIGURE 7.16. Pacific walrus initial behavior during Chukchi Sea marine surveys, 31 Jul–16 Oct 2010. All walrus sightings were in water, n = 44. Behavior codes: DI = Dive, LO = Look (but not specifically at vessel), PO = Porpoise, RE = Rest, SI = Sink, SW = Swim

Mitigation Measures Implemented

Shell's 2010 USFWS LoA for the Chukchi Sea was renewed on 19 May 2010 and its 2010 NMFS IHA was issued on 6 Aug 2010 (Appendices B and A, respectively). Shell did not conduct seismic activities in the Chukchi Sea during 2010, however, the IHA and LoA stipulated numerous general mitigation measures that MMOs implemented throughout the season. These included:

- reducing vessel speed for all Pacific walrus sightings;
- maintaining a 805 m (880 yd or 0.5 mi) marine buffer from all Pacific walruses and polar bears when practicable (this was done for all sightings initially detected at distances greater than 805 m, however, numerous Pacific walruses were initially detected closer than 805 m);
- altering course to avoid separating groups of marine mammals
- reducing vessel speed to less than 10 kt when a cetacean was within or about to be within 274 m (300 yd) of the vessel;
- reducing vessel speed to below 10 kt during periods of poor visibility (e.g., fog) to reduce the risk of injury to marine mammals;
- avoiding multiple alterations of vessel course and speed when groups of marine mammals were encountered;
- checking areas adjacent to vessel propellers for marine mammals before engaging after idle periods;
- transiting outside the polynya zone whenever survey activities were not being conducted.

In addition to specific mitigation measures stipulated in the IHA and LoA, MMOs concentrated their monitoring efforts around all geophysical survey operations, particularly in the areas directly adjacent to survey gear while it was deployed. MMOs aboard the *Ocean Pioneer* conducted a 30-min watch prior to the deployment of the autonomous underwater vehicle (AUV) to ensure that the area to be surveyed was clear of marine mammals.

A juvenile Pacific walrus was observed alongside the *Ocean Pioneer* at a distance of ~100 m (109 yd) on 8 Sep at 1028 as the vessel was stationary and preparing to transit to the next survey site. MMOs communicated with the vessel captain to ensure the walrus was not too close to the vessel before it began transiting. In an attempt to increase the distance from the animal, the vessel began transiting to its next survey location. The walrus began following the vessel and MMOs advised the captain to stop. The vessel was stopped and Shell contacted USFWS to inform them of the situation. The walrus remained in the vicinity of the stationary *Ocean Pioneer* until 1225 when USFWS granted permission for the vessel to transit to its next survey site. The walrus disassociated itself from the *Ocean Pioneer* when the vessel began transiting and the animal was not seen again. There were no other occurrences of marine mammals interacting with vessels or survey equipment during the 2010 Chukchi Sea marine surveys.

Estimated Number of Marine Mammals Present and Potentially Affected

Seismic surveys were not conducted in the Chukchi Sea during 2010 so numbers of exposures of marine mammals to underwater sound levels from seismic pulses were not estimated. Density estimates presented here approximate the number of marine mammals that were present in the study area at the time of the surveys. These animals may have been disturbed to some degree by the presence of project vessels and associated non-seismic survey activities.

Marine Mammal Density Estimates

The numbers of marine mammals visually detected by MMOs likely underestimated the actual numbers that were present (See Chapter 4 and Appendix E). To correct for animals that may have been present but not sighted by observers, the sightings along with detectability corrections $f(0)$ and $g(0)$ were used to calculate densities of marine mammals present in the Chukchi Sea study area. (See Appendix E for detectability correction factors). Marine mammal densities were based on data collected aboard the *Mt. Mitchell, Ocean Pioneer,* and *Arctic Seal* during 2010 Chukchi Sea marine surveys. Marine mammal densities were calculated independently for Jul–Aug and Sep–Oct to account for seasonal changes in the distribution of marine mammals. Table 7.4 presents density estimates for the 2010 Chukchi Sea marine surveys, including 95% confidence intervals.

<u>Cetaceans</u>

Cetacean density estimates based on data collected during the Sep-Oct were more than twice as high as estimates based on data collected during Jul-Aug (Table 7.4). Bowhead whale densities in particular increased from the Jul-Aug to Sep-Oct period, which is consistent with the timing of their fall migration through the Alaskan Chukchi Sea. The increase in gray whale density from Jul–Aug to Sep–Oct was less than for bowhead whales (Table 7.4).

TABLE 7.4. Densities of marine mammals in the Alaskan Chukchi Sea during marine surveys, 31 Jul–16 Oct 2010. 95% confidence intervals are in parentheses. Densities are corrected for *f*(0) and *g*(0) biases.

	No. individuals / 1000 km^2	
Species	Jul-Aug	Sep-Oct
Cetaceans		
Bowhead whale	0.215 (0.024 - 1.959)	4.141 (0.972 - 17.635)
Gray whale	2.366 (0.444 - 12.600)	3.105 (0.748 - 12.886)
Unidentified mysticete whale	1.936 (0.630 - 5.946)	1.449 (0.378 - 5.561)
Unidentified whale	0.000	1.656 (0.291 - 9.417)
Total cetacean density	**4.516 (1.502 - 13.583)**	**10.352 (4.310 - 24.861)**
Seals		
Bearded seal	5.626 (1.055 - 29.990)	9.061 (1.750 - 46.905)
Ringed seal	0.000	5.437 (1.073 - 27.543)
Spotted seal	14.064 (3.220 - 61.429)	1.812 (0.340 - 9.647)
Unidentified pinniped	1.829 (0.340 - 9.823)	0.785 (0.118 - 5.244)
Unidentified seal	11.251 (1.954 - 64.802)	18.122 (3.842 - 85.477)
Total seal density	**32.770 (11.682 - 91.923)**	**35.217 (12.447 - 99.641)**
Pacific walruses	**41.449 (7.197 - 238.718)**	**3.927 (0.969 - 15.914)**

Seals

Seal density estimates remained relatively constant at ~34 seals per 1000 km^2 (~88 seals per 1000 mi^2) throughout the 2010 survey period (Table 7.4). Spotted seal densities were higher in Jul–Aug compared to Sep–Oct, whereas the opposite was true for ringed and bearded seal densities. Many of the seals could not be identified to species, which complicated the interpretation of seal densities by species.

Pacific Walruses

Pacific walrus densities in the offshore Chukchi Sea study area were 91% higher in Jul-Aug than in Sep-Oct 2010 (Table 7.1). During the first week of Sep, aerial survey crews began observing several thousand Pacific walruses hauled out along the Chukchi Sea coast (LGL unpublished data, see NOAA COMIDA data at http://www.afsc.noaa.gov/NMML/cetacean/bwasp/flights_COMIDA.php). It is possible that walrus distribution shifted in response to decreasing sea ice availability. Similar results were recorded in 2007 and 2009 when sea ice concentration in the Chukchi Sea was low during Sep–Oct (Funk et al. 2010).

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Funk, D.W., T.A. Thomas, W.R. Koski, D.S. Ireland, M. Laurinolli, and A.M. Macrander. 2010. Pacific walrus movements and use of terrestrial haul-out sites along the Alaskan Chukchi Sea coast 2006-2008. Alaska Marine Science Symposium, Anchorage Alaska.