MARINE MAMMAL MONITORING AND MITIGATION DURING SITE CLEARANCE AND GEOTECHNICAL SURVEYS BY STATOIL E&P INC. IN THE CHUKCHI SEA, AUGUST–OCTOBER 2011: 90-DAY REPORT

Prepared by

LGL Alaska Research Associates, Inc.
2000 W International Airport Road, Suite C-1, Anchorage, AK 99502

and

JASCO Applied Sciences Ltd.
Suite 2101, 4464 Markham St., Victoria, BC V8Z 7X8, Canada

for

Statoil USA E&P Inc.
3800 Centerpoint, Suite 920, Anchorage, AK 99503

and

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

and

U.S. Fish and Wildlife Service, Marine Mammal Management
1101 E. Tudor Road, M.S. 341, Anchorage, AK 99503

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Edited by

Kris Hartin[a], Lauren Bisson[a], Sarah Case[a], Darren Ireland[a], and David Hannay[b]

[a] **LGL Alaska Research Associates, Inc.**
2000 W International Airport Road, Suite C-1, Anchorage, AK 99502

[b] **JASCO Applied Sciences Ltd.**
Suite 2101, 4464 Markham St., Victoria, BC V8Z 7X8, Canada

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LIST OF ACRONYMS AND ABBREVIATIONS

~	approximately
AKDT	Alaska Daylight Time
AMAR	Autonomous Multichannel Acoustic Recorder
BOEMRE	Bureau of Ocean Energy Management, Regulation and Enforcement
Bf	Beaufort Wind Force
BHA	Borehole Assembly
BSEE	Bureau of Safety and Environmental Enforcement
C	Celsius (degrees)
cm	centimeter
CPA	Closest (Observed) Point of Approach
CPAI	ConocoPhillips Alaska Inc.
CPT	Cone Penetration Test
CTD	Conductivity, Temperature, Depth
dB	decibel(s)
DP	Dynamic Positioning
DPS	Distinct Population Segments
ESA	(U.S.) Endangered Species Act
F	Fahrenheit (degrees)
$f(0)$	sighting probability density at zero perpendicular distance from survey track; equivalently, 1/(effective strip width)
FFT	Fast Fourier Transform
ft	feet
GIS	Geographic Information System
GPS	Global Positioning System
$g(0)$	probability of seeing a group located directly on a survey line
h	hour(s)
HiPAP	High Precision Acoustic Positioning
Hz	Hertz (cycles per second)
IHA	Incidental Harassment Authorization (under U.S. MMPA)
in	inches
in^3	cubic inches
kHz	kilohertz
km	kilometer
km^2	square kilometers
km/h	kilometers per hour
ksps	kilo-samples per second
kt	nautical mile(s) per hour
lb	pound
LOA	Letter of Authorization (under U.S. MMPA)
μPa	micro Pascal
m	meter(s)

MBB	Multibeam Bathymetric (sonar)
mi	statute mile
min	minute(s)
MMO	Marine Mammal Observer
MMPA	(U.S.) Marine Mammal Protection Act
ms	millisecond
n	sample size
NMFS	(U.S.) National Marine Fisheries Service
OBH	Ocean Bottom Hydrophone
OCS	Outer Continental Shelf
psi	pounds per square inch
PTS	Permanent Threshold Shift
rms	Root-Mean-Square: an average, in the present context, over the duration of a sound pulse
RSL	Received Sound Level
s	seconds
s.d.	standard deviation
SEL	Sound Exposure Level: a measure of energy content, in dB re 1 $\mu Pa^2 \cdot s$
SPL	Sound Pressure Level; the SPL for a seismic pulse is equivalent to its rms level
SSV	Sound Source Verification
USBL	Ultra Short Baseline
USFWS	United States Fish and Wildlife Service
UTC	Universal Time, Coordinated
yd	yard(s)

EXECUTIVE SUMMARY

Background and Introduction

This report summarizes the mitigation and monitoring efforts performed by Statoil USA E&P, Inc. (Statoil) during the 2011 site surveys and geotechnical coring in the Chukchi Sea. Statoil conducted both a shallow hazard and site clearance survey and a geotechnical soil investigation in the Chukchi Sea during the 2011 open-water period. The site clearance survey was conducted from the R/V *Duke* and the geotechnical soil investigation survey was conducted from the R/V *Synergy*. The *Duke* towed a small airgun array in addition to other geophysical survey equipment. The *Synergy* drilled boreholes into sediment layers on the seabed to collect soil samples for geotechnical analysis.

Marine seismic surveys and other industrial activities 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.

Statoil's marine geophysical surveys in the Chukchi Sea were conducted under the jurisdiction of an Incidental Harassment Authorizations (IHA) issued by NMFS and a Letters of Authorization (LOA) issued by the USFWS. The IHA and LOA 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 Statoil's marine surveys on marine mammals and subsistence hunting, and to ensure that Statoil was in compliance with the provisions of the IHA and LOA. This required that marine mammal observers (MMOs) onboard the *Duke* 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 *Synergy* implement general mitigation measures as stipulated by the IHA and LOA 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 or coring sounds; and
3. determine the reactions (if any) of marine mammals to industrial sounds.

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

Site Clearance and Geotechnical Surveys Described

Two vessels were used by Statoil in the Chukchi Sea in 2011 in support of shallow hazard site surveys and geotechnical soil investigations. The site survey vessel, *Duke*, used a 4-airgun cluster (4×10 in^3 airguns) and a single 10 in^3 airgun for seismic data acquisition. The Duke also used several other low-energy sources for marine survey activity. The geotechnical soil investigation vessel, *Synergy*, used an open hole drilling configuration to conduct geotechnical borehole sampling.

The geographic region where the shallow hazards site survey occurred was on or near specific Statoil lease holdings in the Chukchi Sea Planning Area designated as Oil and Gas Lease Sale 193. Measurements of underwater sound propogation from the airgun array and other low-energy sources on the *Duke* were conducted by JASCO Research Ltd. (JASCO) on 8 Aug. JASCO calculated preliminary disturbance and safety radii within 5 days of completion of the measurements. These radii were the basis for implementation of mitigation by MMOs during seismic survey activities thereafter. The *Duke* collected seismic data along ~4482 km (2714 mi) in the Chukchi Sea, which began with airgun testing on 7 Aug and continued through 20 Sep.

The geotechnical soil investigation survey occurred on the same Statoil leases as the site survey activities, as well as, on jointly owned Statoil and ConocoPhillips Alaska Inc. (CPAI) lease holdings in the Chukchi Sea. After an initial delay due to poor weather conditions, JASCO conducted measurements of underwater sound produced by the *Synergy's* activities on 9 Sep. The *Synergy* completed 18 geotechnical coring boreholes at six sites; five sites were on Statoil leases and one site was on a jointly owned Statoil-CPAI lease in the Chukchi Sea between 5 Sep and 27 Sep.

Vessel-based marine mammal monitoring was conducted from the *Duke* and the *Synergy* throughout the operations in the Chukchi Sea. Marine mammal observers aboard each vessel collected data, requested mitigation measures, as necessary, and ensured both vessels operated in accordance with the provisions of the IHA and the LOA.

Underwater Sound Measurements

As a part of the 2011 operations, Statoil was required to measure and report underwater sound levels from its offshore survey operations. JASCO Applied Sciences carried out the monitoring studies on behalf of Statoil in August and September 2011. 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.

Statoil's 2011 IHA stipulated a requirement to measure underwater sound levels in the 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. Statoil's 2011 IHA also included measurement requirements for characterizing high frequency sonar sounds.

The acoustic measurements for the site survey and geotechnical soil investigation programs were performed from the survey vessel R/V *Duke*. The sound sources characterized from the site survey program included a 40 in^3 airgun array consisting of four 10 in^3 airguns that were fired simultaneously and a single 10 in^3 airgun that was fired between shots from the 40 in^3 airgun array. The single 10 in^3 airgun was also used as a mitigation source during turns and on line approaches to encourage marine mammals to stay away from the survey vessel and avoid being exposed to higher-level sounds from the 40 in^3 array when it was ramped up. The site survey program also employed a sub-bottom profiler, underwater acoustic positioning system, and single beam, multibeam and side-scan sonars. All of the above sources and vessel self-noise from the *Duke* were measured in this study.

The geotechnical soil investigation program sound sources included a single-beam sonar, underwater acoustic positioning system, and vessel noise from the R/V *Fugro Synergy* while in dynamic positioning (DP) during and in the absence of coring operations. All of the above sources and vessel self-noise from *Synergy* were characterized as part of the sound measurement study.

Two types of seabed-deployed sound measurement equipment were used for this study. Measurements of sounds below 24 kHz were made with Ocean Bottom Hydrophone (OBH) systems. Each OBH system recorded two channels of acoustic data sampled at 48 ksps using a lower sensitivity Reson TC4043 hydrophone and a higher sensitivity Reson TC4032 hydrophone. Higher frequency sources were measured with an Autonomous Multi-channel Acoustic Recorder (AMAR), recording at 687.5 ksps with a Reson TC4014 hydrophone. All hydrophones were calibrated by Reson. 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 from the sources of the site survey and geotechnical soil investigation programs are given below in Table 1 and Table 2, respectively. Source spectra, 1/3-octave band received and source levels, and sound level versus range plots are included in Chapter 3 of this report.

Table 1. Sound level threshold distances for sources from the Shallow Hazards program, based on 90th percentile fits to measurement data. All sources were operated from the *Duke*.

90% rms SPL (dB re 1 µPa)	*190*	*180*	*170*	*160*	*120*
40 in^3 airgun array range (m)	*37*	*130*	*460*	*1500*	*30000**
10 in^3 airgun range (m)	*15***	*59*	*230*	*840*	*29000**
Single beam range (m)			*38†*	*40†*	*1000*
Sub-bottom profiler range (m)				*30†*	*450*
Side-scan sonar range (m)	*22*	*47*	*100*	*230*	*5100**
Multibeam sonar range (m)					*330**
SonarDyne positioning system range (m)	*7***	*13***	*25***	*47*	*470*
SonarDyne beacon range (m)				*26*	*750‡*
Duke transiting at 4.5 kts range (m)				*11***	*4200**

*Extrapolated beyond maximum measurement range.

**Extrapolated beyond minimum measurement range.

†Actual maximum slant range that the threshold was exceeded. Not from fit function.

‡Though less than the extrapolated out-of-beam distance, the measured in-beam distance is considered to be more accurate.

Table 2. Sound level threshold distances for sources from the Geotechnical Soil Investigation program, based on 90th percentile fits to measurement data. All sources were operated from the *Synergy*.

90% rms SPL (dB re 1 µPa)	*190*	*180*	*170*	*160*	*120*
Single beam (18 kHz) range (m)	*6**	*11**	*19**	*34**	*340*
Single beam (200 kHz) range (m)	*12**	*16**	*21**	*27**	*75*
HiPAP (22/23 kHz) positioning system range (m)	*4**	*9**	*20**	*44**	*1000*
HiPAP (21/21.5 kHz) positioning system range (m)		*1**	*3**	*7**	*370*
Synergy in DP without coring range (m)			*1**	*6**	*2300***
Synergy in DP during coring range (m)				*2**	*1800***
Synergy transiting at 4.5 kts range (m)				*1**	*1600*

*Extrapolated beyond minimum measurement range.
**Extrapolated beyond maximum measurement range.

Marine Mammal Monitoring

Site Surveys – Duke

During the Statoil site survey, MMOs observed a total of 11 sightings of 35 cetaceans, 109 sightings of 111 seals, no sightings of polar bears, and 61 sightings of 98 Pacific walrus. Gray whales were the most frequently identified cetacean. Bearded seals were the most frequently identified seal species, although nearly a third of the seals sighted could not be identified to species.

Only one of the eleven cetacean sightings occurred while airguns were active, and in that case only the single mitigation airgun was operating. The majority of cetacean sighting occurred during the trip to Wainwright on 28 August, when the vessel was off of the site survey area and therefore was not operating the airguns.

The majority of walrus sightings occurred on two separate days: 18 August (25 sightings) and 28 Aug (19 sightings). On 18 Aug the *Duke* was on the survey site and the high number of sightings was likely due to the movement of Pacific walruses toward haul outs on the Alaskan Chukchi Sea coast. Sightings made on 28 Aug occurred during the vessel transit to Wainwright and the proximity to land and potential foraging areas of walrus using shore haul outs likely resulted in the high number of Pacific walrus sightings.

The movement of all 11 cetaceans relative to the *Duke* was either unknown or neutral. Only one cetacean was sighted during seismic activity (mitigation airgun firing) and it was observed moving neutral relative to the vessel. No cetaceans sighted from the *Duke* exhibited an overt (or discernible) reaction to the vessel regardless of seismic activity.

Most of the seal movements recorded during Statoil's seismic survey were neutral relative to the vessel (~57%). Nearly twice as many seals were seen swimming away than swimming towards the *Duke.* Seals observed from the *Duke* were most often recorded as having no reaction (~48%), while the second-most observed reaction was of seals looking at the vessel (~35%).

Movements neutral relative to the vessel were the most commonly recorded movements of Pacific walruses from the *Duke* during Statoil's site survey. Walruses observed from the *Duke* were most often recorded has having no reaction (~39%) to the vessel or airguns. The second-most observed reaction (~31%) was of walruses looking at the vessel.

There were 17 total marine mammal sightings during ramp up periods. All sightings were of pinnipeds: six Pacific walruses, one ringed seal, four bearded seals, three unidentified pinnipeds, and three unidentified seals. The reactions of these pinnipeds during ramp up were similar in proportion to reactions during seismic and non-seismic activity. The fastest pace of marine mammals sighted during ramp up was moderate, and no comments made about sightings during ramp up periods describe agitation or abnormal behavior.

Three power downs and one shutdown were requested during the Statoil site survey as a result of Pacific walrus sightings within or approaching the applicable safety radius. No power downs or shut downs of the airguns were necessary for cetaceans or seals. All power downs occurred during a 2-day period, 17–19 Aug, when walrus sightings were most numerous. Each of the power downs occurred when the array was operating at full volume (40 in^3). One complete shutdown was implemented during the seismic survey. The shutdown occurred on 15 Aug for an unidentified pinniped carcass which was later determined to be a Pacific walrus carcass in an advanced state of decomposition.

Based on direct observations, no cetaceans, 68 seals, and 57 walruses were likely exposed to airgun sounds above the 160 dB (rms) disturbance threshold. No seals were observed within the ≥190 dB (rms) distance and two walruses were likely exposed to ≥180 dB (rms) which resulted in power downs of the four airgun cluster to the single mitigation airgun.

Based on densities calculated from sighting rates during non-seismic periods, approximately 21 individual cetaceans, mostly gray whales, would each have been exposed to airgun pulses with RSLs ≥160 dB (rms) during the survey if they showed no avoidance of active airguns or vessels. Density based calculations also estimated that ~169 individual seals may have been exposed to airgun pulses with RSLs ≥160 dB (rms) during the survey, including ~80 bearded seals, ~46 ringed seals, ~3 spotted seals, and ~42 individual pinnipeds of unknown species. An estimated ~132 individual walruses were potentially exposed to airgun pulses with RSLs ≥160 dB (rms) during the survey.

Geotechnical Coring – Synergy

During the Statoil geotechnical coring operations, MMOs aboard the *Synergy* recorded five cetacean sightings of eight individuals, 12 sightings of 12 seals, and 20 sightings of 49 individual Pacific walruses. The majority of these sightings occurred while the vessel was in transit to and from Wainwright.

The *Synergy* had 14 sightings that were either too brief, too distant, or occurred during periods of low visibility to accurately identify to the animal to species. It is likely that two of the three unidentified mysticete whale sightings were gray whales. Of the 10 unidentified pinnipeds and seals, one was likely a bearded seal and the other was likely a Pacific walrus.

Of the five cetacean sightings on the *Synergy*, four occurred while the vessel was in transit to/from Wainwright. All four cetaceans sighted during transit were either not moving, moving neutral relative to the vessel, or had unknown movement relative to the vessel. One cetacean sighting occurred while the *Synergy* was stationary but not coring and that animal was observed swimming away from the vessel. No cetaceans sighted from the *Synergy* exhibited an overt (or discernible) reaction to the vessel.

Of the 12 seal sightings observed from the *Synergy*, eight occurred while the vessel was moving in transit to/from Wainwright. Movement relative to the vessel was unable to be determined in eight cases, while neutral movement and swimming away were exhibited in the remaining sightings. While the vessel was stationary in dynamic positioning mode, one seal was observed swimming towards and one away from the vessel. Seals observed from the *Synergy* while it was underway were most often recorded as splashing, looking at the vessel, and changing direction. Seals observed from the *Synergy* while stationary in dynamic positioning mode with or without ongoing coring operations had no apparent reaction to the vessel.

Movements that were neutral relative to the vessel or no movement were the most common recorded movements of Pacific walrus observed from the *Synergy*. Walruses observed from the *Synergy* most frequently reacted to the vessel by looking at it, both while the vessel was moving (~71%) and while it was stationary (~67%). The second-most commonly observed reaction was a change in direction.

A total of three mitigation actions were requested and implemented on the *Synergy* during Statoil's 2011 geotechnical survey in the Chukchi Sea. Two were related to general vessel operations during transits and involved requests to reduce vessel speed to mitigate approaches to cetaceans on 9 Sep and walruses on 22 Sep. The third was a precautionary mitigation request for heighten monitoring of the vessel's moonpool. This was implemented during geotechnical coring operations on 10 Sep due to the ~14 h presence of a walrus in the waters around the *Synergy*.

Based on direct observations, one cetacean, four seals, and four Pacific walruses may have been exposed to received levels of continuous sounds ≥120 dB (rms). Based on densities calculated from sighting rates during non-seismic periods, one cetacean, 17 seals, and six walruses may have been exposed to continuous sounds with RSLs ≥120 dB (rms) during the coring or dynamic positioning activities.

Summary of Marine Mammals Potentially Effected

Based upon direct observation, zero cetaceans were likely exposed to either ≥160 dB (rms) pulsed sound from seismic activity or ≥120 dB (rms) continuous sound from coring operations. Using density estimates, ~21 individual cetaceans, mostly gray whales, may have been exposed to RSLs at or above these thresholds if they showed no avoidance of the operations. This is still less than the estimates provided in the IHA application.

Sixty-eight and four seals were likely exposed to received sound levels ≥160 dB (rms) from seismic activity and ≥120 dB (rms) from coring operations, respectively, based on direct observation. No seal sightings occurred within the ≥190 dB (rms) safety radius of the seismic operation, so no power downs or shutdowns were requested for seal sightings. Using density estimates, ~185 seals, including ~91bearded seals, ~48 ringed seals and ~ 3 spotted seals, may have been exposed to RSLs at or above the disturbance thresholds. These estimates are lower for ringed and spotted seals than those estimated in the IHA application. The estimated number of bearded seals exposed to these sounds levels is higher than that estimated in the IHA application. This is primarily due to the higher than expected density of bearded seal during the fall period at times when airguns were active.

Direct observation of Pacific walrus indicate that 57 individuals were likely exposed to ≥160 dB (rms) from seismic activity and three individuals were likely exposed to continuous sound ≥120 dB (rms) from coring operations. Using density estimates, ~138 walruses may have been exposed to RSLs at or above the ≥160 dB (rms) threshold for pulsed airgun sounds or the ≥120 dB (rms) threshold for continuous sounds from coring operations.

Night Observations

Observers on both vessels commonly performed observations at night using night vision devices (NVDs) to continue to test and assess their usefulness for monitoring in darkness. Observers occasionally sighted jellyfish and seabirds if they were near the vessel and the sighting conditions were good. Only two marine mammal sightings were made using NVDs and both sightings were of Pacific walrus sighted by observers on the *Synergy*.

The lack of nighttime sightings, especially from the *Duke*, was likely due to the limitations of the observers (eye fatigue) and of the devices to perform in various environmental conditions (i.e. high sea states or fog, areas on the vessel free from excessive light or glare). The observers concluded that the NVDs were most useful when there was still a small amount of ambient light present. Observers on the *Duke* estimated the device's effective range to be between 10 m (33 ft) and 500 m (1640 ft), depending on the lighting and environmental conditions, and could be used for roughly half of their night observation shift (10-15 min with NVDs followed by equal time with unaided eye).

In 2010, Statoil conducted observations from their seismic survey vessel, *Geo Celtic*, using an experimental (not commercially available) 360° infrared (IR) camera. The IR camera system had environmental limitations similar to NVDs (ineffective in fog, high sea state, etc.), but it did have the advantages of displaying images on three high resolution computer monitors (reducing eye fatigue), automatically detecting potential sightings (a software tool still under development and refinement), and allowing the observer to record all or segments of the video stream. As noted above, this system is not commercially available at this time and although it is a promising technology, it will require further testing and evaluation before it can be implemented as a regular monitoring tool.

A recommended next step in evaluating these two technologies would be to conduct observations with a pair of observers utilizing both a commercially available IR system and an optical NVD system. Under such a scenario the IR observer may be able to detect marine mammals more consistently and experience less eye fatigue while the optical observer could confirm observations and potentially identify the species of marine mammal.

Acoustic Detections by Anchored Hydrophones and Visual Observations during the 2010 Seismic Survey

In response to a request by the NMFS peer review panel, a comparison was attempted between visual observations and acoustic detections of marine mammals during Statoil's 2010 seismic survey operations. Bowhead whale calls were the only marine mammal calls that could be localized using the cluster of hydrophone recorders deployed on Statoil's leases. Bowhead calls localized on the Statoil leases did not occur until several days after the seismic survey had ended and. Bowhead whale calls localized by the cluster of acoustic recorders on Statoil's leases were necessarily limited to that area, while bowhead whales observed from vessels were detected closer to the coast during transits to and from Wainwright.

The majority of acoustic detections of bearded seal vocalizations occurred after vessels left the survey area. The highest periods of visual observations of bearded seals did not occur in conjunction with high numbers of acoustic detections.

Increased acoustic detections of Pacific walrus vocalizations did correspond to the high number of Pacific walrus observations between 28 and 31 Aug 2010, as a large number of walrus moved from the receding ice edge towards the Alaskan Chukchi Sea coast. Counts of walrus calls remained high throughout early to mid- Sep 2010 at recorders closer to Wainwright than the survey area; however, a corresponding high rate of visual detections at the seismic survey site was less evident.

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Harriett Nungasak	

1. BACKGROUND AND INTRODUCTION[1]

This report summarizes the mitigation and monitoring efforts performed by Statoil USA E&P, Inc. (Statoil) during the 2011 site surveys and geotechnical coring in the Chukchi Sea.

Marine seismic surveys and other industrial activities emit sound energy into the water (Greene and Richardson 1988; Richardson et al. 1995; Tolstoy et al. 2004, Tolstoy et al. 2009) 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 very close to the sound source) temporary or permanent reduction in hearing sensitivity. Potential effects, however, may be reduced by marine mammals moving away from approaching sound sources (Reiser et al. 2009; Richardson et al. 1995, 1999; Stone and Tasker 2006; Gordon et al. 2004; Smultea et al. 2004). 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."

A number of species of cetaceans and pinnipeds inhabit parts of the Chukchi Sea. The National Marine Fisheries Service (NMFS) and the U.S. Fish and Wildlife Service (USFWS) split jurisdiction over the marine mammal species that could be encountered during offshore industrial activities in this region. Three species under NMFS jurisdiction that may occur there are listed as "Endangered" under the ESA, including bowhead whale (*Balaena mysticetus*), humpback whale (*Megaptera novaeangliae*), and fin whale (*Balaenoptera physalus*). Additionally, NMFS initiated a status review to determine if listing as endangered or threatened under the ESA is warranted for four other species including ringed seal (*Phoca fasciata*), spotted seal (*Phoca largha*), bearded seal (*Erignathus barbatus*), and ribbon seal (*Histriophoca fasciata*; NMFS 2008a,b). Subsequently, NMFS (2008a) announced that listing of the ribbon seal as threatened or endangered was not warranted at this time. More recently, NMFS (2010a) determined that no listing action was warranted for the Bering Sea and Okhotsk populations of spotted seal. NMFS (2010b) determined that two distinct population segments (DPS) of bearded seals, the Beringia and Okhotsk DPSs, should be listed as a threatened species, but extended the public comment period for the listing. NMFS (2010c) also designated four subspecies of ringed seal, including Arctic, Okhotsk, Baltic, and Ladoga, as proposed threatened species but extended the public comment period for these listings as well. USFWS manages two marine mammal species occurring in the Chukchi Sea, the Pacific walrus (*Odobenus rosmarus*) and polar bear (*Ursus maritimus*). The polar bear was recently listed as threatened under the ESA (USFWS 2008). A petition to list Pacific walrus as threatened or endangered was submitted to USFWS (CBD 2008) and resulted in the species being designated as a candidate species on the ESA (USFWS 2011).

Because of the potential for marine mammals to be encountered during planned site surveys and geotechnical coring in the Chukchi Sea during the 2011 open-water season, Statoil USA E&P, Inc. (Statoil) submitted an application to NMFS on 1 March 2011 for an Incidental Harassment Authorization (IHA) to authorize non-lethal "takes" of marine mammals incidental to Statoil's proposed activities. A notice announcing Statoil's request for an IHA was published in the *Federal Register* on 24 May 2011 and public comments were invited (NMFS 2011). An IHA allowing the proposed activities in the Chukchi Sea was issued to Statoil by NMFS on 28 July 2011 which allowed operations to be conducted

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[1] By Lauren Bisson, Sarah Case, Kris Hartin (LGL Alaska Research Associates, Inc.)

from 1 Aug 2011 through 30 November 2011. The IHA authorized "potential take by harassment" of various cetacean and seal species during the site clearance (seismic) survey described in this report.

Similarly, on 8 April 2011, Statoil requested a Letter of Authorization (LOA) from USFWS for the incidental "take" of polar bears and walrus during open-water exploration activities in the Chukchi Sea in 2011. A notice announcing Statoil's request for an LOA was published in the *Federal Register* on 15 Mar 2011 and public comments were invited. The USFWS issued a LOA on 28 Jun 2011 allowing Statoil to "take" small numbers of polar bears and Pacific walruses incidental to proposed activities occurring during the 2011 Chukchi Sea open-water season. The LOA was valid from 1 Aug 2011 through 30 Nov 2011.

Having received the necessary authorizations, as well as an ancillary activities permit from the Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE; now Bureau of Safety and Environmental Enforcement [BSEE] and Bureau of Ocean Energy Management [BOEM]) Statoil collected shallow hazards marine seismic data and geotechnical soil investigation samples (cores) in the Chukchi Sea during the open-water period of 2011 in support of potential future oil and gas exploration and development. Seismic acquisition for Statoil was conducted by Gardline CGGVeritas using the M/V *Duke*, a seismic vessel that towed an airgun array as well as hydrophone streamers to record seismic data. Geotechnical samples were collected by Fugro-McClelland Marine Geosciences, Inc. using the M/V *Synergy* to conduct geotechnical coring and sampling.

This document serves to meet reporting requirements specified in the IHA and LOA. The primary purposes of this report are to describe project activities in the Chukchi Sea, 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 survey activities at or above presumed effect levels as prescribed by the respective agencies.

Incidental Harassment Authorization and Letter of Authorization

IHAs typically include provisions to minimize the possibility that marine mammals close to the sound 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, strong sounds were generated by *Duke*'s airgun array in order to collect shallow hazards seismic data on and near Statoil's lease holdings in the Chukchi Sea. Sounds were also generated by the *Synergy*'s dynamic positioning system and coring equipment while on proposed borehole sites in the Chukchi Sea. Given the nature of the operations and mitigation measures, no serious injuries or deaths of marine mammals were anticipated as a result of the activities, and no such injuries or deaths were attributed to these activities. Nonetheless, the seismic survey and geotechnical coring operations described in Chapter 2 had the potential to "take" marine mammals by harassment. Certain behavioral disturbances to marine mammals are considered to cause "take by harassment" under the provisions of the MMPA.

Under current NMFS guidelines (e.g., NMFS 2011), "safety radii" for marine mammals around airgun arrays and other sound sources are customarily defined as the distances within which received sound levels are ≥180 decibels (dB) re 1 μPa (rms)[2] for cetaceans and ≥190 dB re 1 μPa (rms) for

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[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. 2000a,b). The

pinnipeds. Those safety radii are based on an assumption that seismic pulses or other sounds 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 the safety radii if the mammals were exposed to moderately strong pulsed sounds generated by the airguns or perhaps by vessel or coring sounds (Richardson et al. 1995). The NMFS assumes that marine mammals exposed to pulsed airgun sounds with received levels ≥160 dB re 1 µPa (rms) or continuous sounds from coring activities with received levels ≥120 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). In general, disturbance effects are expected to depend on the species of marine mammal, the activity of the animal at the time of exposure, 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 for pulsed sounds, 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 (rms; Miller et al. 1999). 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. 2008). Beluga whales may, at times, also show avoidance at received levels below 160 dB (rms; Miller et al. 2005). In contrast, bowhead whales on the summer feeding grounds 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).

The IHA issued by NMFS to Statoil authorized incidental harassment "takes" of three ESA-listed species including bowhead, humpback, and fin whales, as well as several non-listed species including gray whale (*Eschrichtius robustus*), Minke whale (*Balaenoptera acutorostrata*), killer whale (*Orcincus orca*), narwhal (*Monodon monoceros*), beluga whale (*Delphinapterus leucas*), harbor porpoise (*Phocoena phocoena*), and ringed, spotted, bearded, and ribbon seals.

NMFS granted the IHA to Statoil on the expectation that

- the numbers of whales and seals potentially harassed (as defined by NMFS criteria) during seismic and coring 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

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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" (SEL) 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. 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.

- the agreed upon monitoring and mitigation measures would be implemented.

The LOA issued to Statoil by USFWS was based on similar expectation as described for the IHA, and required Statoil to observe a 190 dB (rms) safety radius for polar bears and a 180 dB (rms) safety radius for walruses.

Mitigation and Monitoring Objectives

The objectives of the mitigation and monitoring program were described in detail in Statoil's IHA and LOA applications (Statoil 2011a,b) and in the IHA and LOA issued to Statoil (NMFS 2011a,b) An explanation of the monitoring and mitigation requirements was published by NMFS in the *Federal Register* (NMFS 2011a).

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 or coring sounds; and
- determine the reactions (if any) of marine mammals potentially exposed to industrial sounds.

Mitigation and monitoring measures that were implemented during the activities in the Chukchi Sea are described in detail in Chapter 4.

The purpose of the mitigation program was to avoid or minimize potential effects of Statoil's site clearance survey and geotechnical coring on marine mammals and subsistence hunting. This required that shipboard personnel 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 Pacific walrus], and in such cases initiate an immediate power down (or shut down if necessary) of the airguns. A power down involves reducing the source level of the operating airguns, in this case by reducing the number of airguns firing. A shut down involves temporarily terminating the operation of all airguns. Additionally, the safety radii were monitored in good visibility conditions for 30 minutes prior to starting the first airgun and during the ramp up procedure to ensure that marine mammals were not near the airguns when operations began (see Chapter 4).

Mitigation measures within the 160 dB (rms) isopleth were also required, as described in the IHA issued by NMFS, for an aggregation of 12 or more non-migratory mysticete whales and in the LOA issued by USFWS for aggregations of 12 or more Pacific walruses. Power down of the seismic airgun array was required if an aggregation of 12 or more non-migratory mysticete whales or Pacific walruses were detected a within the 160 dB (rms) isopleth.

Report Organization

This 90–day report summarizes the site survey activities and describes the methods and results of the mitigation and monitoring performed to meet the above objectives as required by the IHA and LOA.

This report includes seven chapters:

1. background and introduction (this chapter);
2. description of Statoil's site survey and coring operation;
3. acoustic sound source measurements during the field season;

4. description of the marine mammal monitoring and mitigation program and the data analysis methods;
5. results of the marine mammal monitoring from the site survey vessel *Duke* and estimates of potential "take by harassment";
6. results of the marine mammal monitoring from the geotechnical coring vessel *Synergy* and estimates of potential "take by harassment";
7. summary of monitoring results and estimates of potential "take by harassment" from both vessels.

In addition, there are ten appendices that provide copies of relevant documents and details of field procedures and data analysis methods and results. The appendices include

A. descriptions of vessels and equipment;
B. sound source measurement results;
C. details of monitoring, mitigation, and analysis methods;
D. Beaufort wind force definitions;
E. marine mammal status and abundance in the Chukchi Sea;
F. marine mammal monitoring results during the Chukchi Sea surveys;
G. list of all marine mammal detections;
H. unidentified marine mammal detections;
I. weekly summary maps of vessel activity;
J. NMFS Marine Mammal Stranding Reports for carcasses observed in 2011.

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2. SITE SURVEY AND GEOTECHNICAL CORING OPERATIONS DESCRIBED[1]

Operating Areas and Dates

Marine mammal monitoring was conducted from two vessels operated by Statoil in the Chukchi Sea in 2011 in support of shallow hazards site surveys and geotechnical soil investigations (coring). The site survey vessel (M/V *Duke*) used a 4-airgun cluster (4×10 in^3 airguns) and a single 10 in^3 airgun for seismic data acquisition. The geotechnical coring vessel (M/V *Synergy*) utilized an open hole drilling configuration to conduct geotechnical borehole sampling. Detailed descriptions of these vessels and their equipment can be found in Appendix A. Marine mammal observers (MMOs) aboard the *Duke* and the *Synergy* collected data and requested mitigation measures, as necessary, during the operations. Both vessels operated in accordance with the provisions of the IHA issued by NMFS and the LOA issued by USFWS. Additionally, Statoil followed prescribed communication protocols with the Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE)

Site Clearance Surveys

The geographic region where the shallow hazards site survey occurred was on or near Statoil lease holdings in the Chukchi Sea Planning Area designated by Oil and Gas Lease Sale 193. These leases are located ~240 km (150 mi) west of Barrow and ~160 km (100 mi) northwest of Wainwright in Outer Continental Shelf (OCS) waters averaging 30–50 m (33-55 yd) deep and outside the polynya zone. The shallow hazards site surveys were designed to meet the standards provided by BOEMRE in the Notice to Lessees number 05-A01.

The site survey vessel *Duke* left Dutch Harbor on 1 Aug and entered the Chukchi Sea "survey area" (the area north of Point Hope, 68.34ºN latitude) on 6 Aug. Statoil's seismic contractor, Gardline CGGVeritas, deployed the seismic acquisition equipment and began testing the equipment on 7 Aug. JASCO Applied Sciences (JASCO) conducted measurements of the underwater sound produced by the airgun array, mitigation airgun, and high frequency sound sources on 8 Aug. Acoustic measurements were conducted at Statoil's exploration lease area in the Chukchi Sea, ~190 km (118 mi) northwest of Wainwright (see Chapter 3 for a complete description of the sound source measurements and analysis). JASCO calculated preliminary disturbance and safety radii within 5 days of completion of the measurements. These radii were the basis for implementation of mitigation by MMOs during seismic survey activities thereafter.

The *Duke* collected seismic and other bathymetric data in the Chukchi Sea from 9 Aug through 20 Sep. Transit to and from the village of Wainwright for an unplanned crew change occurred on 28 August. The *Duke* departed the Chukchi Sea on 23 Sep arriving in Dutch Harbor on 25 Sep. Statoil completed ~4482 km (2714 mi) of seismic data acquisition in the Chukchi Sea in 2011.

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[1] By Kris Hartin, Lauren Bisson, Sarah Case (LGL Alaska Research Associates, Inc.)

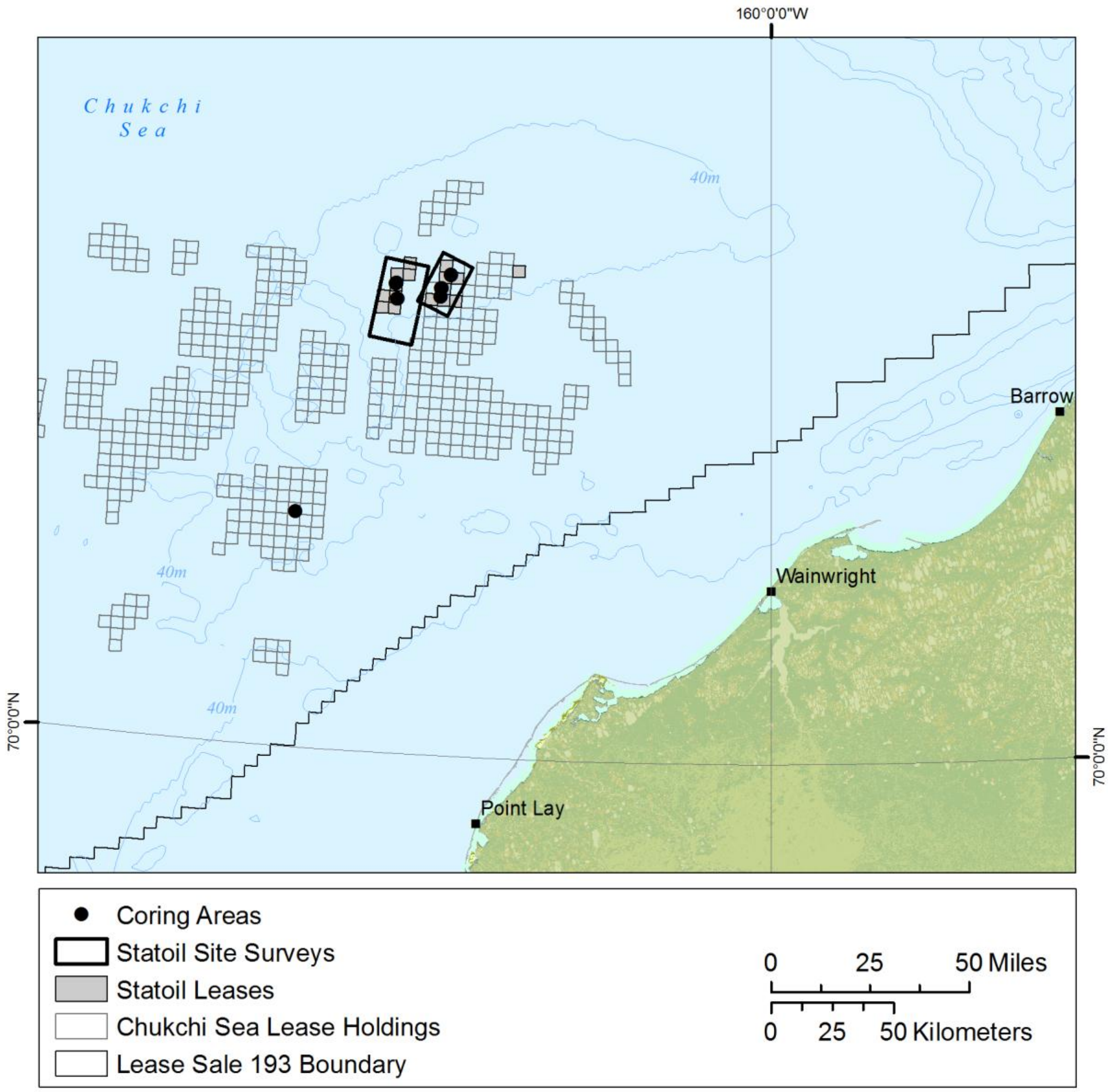

FIGURE 2.1. Location of the site clearance and seismic survey activity (bold outline) and borehole sites (blackdots). The boundary of the polynya is shown by the thin black line which also delineates the boundary of Lease Sale Area 193.

On each seismic line, 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. Periods of full array firing including periods of lead in, lead out, seismic testing, and ramp up occurred along ~3202 km (1990 mi) of trackline. During turns from one seismic line to the next, testing of a single airgun, or during power down periods for marine mammals observed within the safety radii of the full airgun array, the single mitigation gun was operated along ~1760 km (1094 mi) of vessel trackline. Thus, one or more airguns were operated along ~ 4962 km (3083 mi) of total trackline in the Chukchi Sea in 2011.

Throughout the survey, the *Duke's* position and speed were logged digitally every ~60 s. In addition, the position of the *Duke*, water depth, environmental information, and information on the number and volume of airguns that were firing were collected by the MMOs while on duty. This includes when the *Duke* was offline (e.g., prior to shooting at full volume) or was online but not recording data (e.g., during airgun or seismic data recording equipment problems).

Geotechnical Coring Operations

The geotechnical soil investigation survey occurred on the same Statoil leases as the site survey activities, as well as, on jointly owned Statoil and ConocoPhillips Company (COP) lease holdings in the Chukchi Sea. A total of 17 geotechnical cores were collected at 5 potential drill sites on Statoil leases and a single additional geotechnical core was collected on a Statoil-COP lease located ~188 km (117 mi) northwest of Wainwright and ~304 km (189 mi) west of Barrow in waters 42 m (138 ft) in depth.

The geotechnical coring vessel *Synergy* left Dutch Harbor on 31 Aug and entered the Chukchi Sea survey area on 3 Sep. The *Synergy* arrived at its first location and commenced geotechnical coring operations on 5 Sep. On 9 Sep, after a delay caused by poor weather conditions, JASCO conducted sound source verification (SSV) measurements of underwater sounds generated by the *Synergy* including a dual-frequency echosounder, High Precision Acoustic Positioning (HiPAP) system, vessel self-noise during transits, vessel in dynamic positioning (DP) mode, and active coring operations in DP mode. JASCO calculated preliminary disturbance and safety radii within 5 days of completion of the measurements. As expected, the source levels and/or mitigation threshold distances from these sound sources did not require mitigation "shut downs" or "power downs" of the equipment or operations. However, MMOs monitored during all daylight activities for animals occurring close to the vessel that had the potential to interact with the vessel's equipment and/or operations.

The *Synergy* continued geotechnical coring operations in the Chukchi Sea until 27 Sep. Transits to and from the village of Wainwright occurred on 16 Sep for an unplanned crew change and on 22 Sep to take onboard a technician for an equipment repair. While transiting to and from the worksite, the village of Wainwright, and between coring locations, the *Synergy* traveled ~1846 km (1147 mi) in the Chukchi Sea. The *Synergy* completed coring operations and departed the Chukchi Sea on 26 Sep and arrived in Dutch Harbor on 30 Sep. The *Synergy* was stationary using dynamic positioning for ~498 hours (h), which included ~343 h conducting coring operations. A total of 18 geotechnical coring boreholes at six sites were completed by the *Synergy*; five of those sites were on Statoil leases, and one was on a jointly owned Statoil-COP lease in the Chukchi Sea. A single additional borehole was attempted at one of the Statoil locations but was cancelled before coring commenced due to a mechanical issue.

Throughout the *Synergy's* geotechnical soil investigation survey, the vessel's position, survey activity, water depth, and environmental information were collected by the MMOs while on duty. This includes all periods of transit in the Chukchi and Bering Seas. In addition, the vessel's position was logged digitally every ~60 s during all transits and survey activities.

Airgun and Sonar Description

The site survey vessel *Duke* towed a 40 in^3 airgun cluster (4 × 10 in^3 airguns) and a separate 10 in^3 airgun at ~2 m (2 yd) depth and ~60 m (66 yd) behind the vessel, as well as additional lower powered and higher frequency survey equipment. The four 10 in^3 airguns were arranged in a rectangular configuration. The single 10 in^3 airgun was used as the mitigation gun and was fired between lines to discourage marine mammals from approaching the vessel. While collecting seismic data on a survey line, the airgun cluster and the single airgun were fired alternately on consecutive shots, sometimes referred to as a flip-flop pattern.

The higher frequency sonar survey equipment included a Kongsberg SBP3000 sub-bottom profiler, a GeoAcoustics 160D side-scan sonar, a Sonardyne Ranger Pro Ultra Short Baseline (USBL) system, a Simrad single beam EA502 echosounder, and a Kongsberg EM2040 multi-beam echosounder. All of this equipment is considered industry standard for site surveys and was mounted on the *Duke's* hull except the side-scan sonar. The multi-beam echosounder, the single beam echosounder, and sub-bottom profiler operated for the majority of the survey when the *Duke* was on the survey site; however, those three instruments were routinely turned off for transit to Wainwright, during bad weather, and during occasional equipment malfunctions. For vessel safety, the *Duke's* single beam navigational echosounder was activated when the Simrad single beam echosounder was deactivated. The side-scan sonar was towed behind the *Duke* at a depth of ~18.5 m (61 ft) and was typically only activated when the airguns were operating. The USBL system, similar to the HiPAP system on the *Synergy*, was used to localize the side-scan sonar relative to the vessel and was activated only when the side-scan sonar was operating. Please refer to Chapter 3 for detailed descriptions of the operating frequencies of all sound sources operated during the site surveys and geotechnical coring.

Geotechnical Coring Equipment

Geotechnical coring was performed by the *Synergy*, a class 2 dynamic positioning vessel utilizing global positioning system (GPS), taut wire, and a high precision acoustic positioning (HiPAP) system for referencing and maintaining a fixed position during coring activities. Potential sound sources from the *Synergy* included the tunnel and azimuth thrusters when the vessel was in dynamic positioning mode, a Kongsberg EA600 Single Beam Echosounder for referencing water depth, and a Kongsberg HiPAP 500 transducer for referencing the vessel's position relative to a beacon affixed to the seabed frame. The seabed frame is a structure lowered to the seafloor during coring that provides stability to the drill string, aids in positioning the vessel over the borehole, and serves as a reactive mass for sediment testing. Equipment on the vessel which likely contributed to sound energy entering the water during coring activity included the hydraulic semi-automated pipe handling deck, a 250 ton capable top drive, and 5000 psi pressurization mud pump systems

Geotechnical coring boreholes were completed using an open hole system that utilized a seawater and guar gum (a non-toxic plant extract) drilling mud for viscosity. Boreholes were created with a 9.25 inch (in) diameter 5-wing drag bit affixed to a 7 in diameter Borehole Assembly (BHA) and 5.5 in outer diameter drill pipe sections. Geotechnical soil sampling was achieved via a push sampler, a Cone Penetration Test (CPT) tool, and a temperature probe. Borehole drilling, coring, and sampling activities occurred through a 7.5 X 7.5 m (~8 X 8 yd) moon pool located mid ship on the drilling deck.

Boreholes created by the *Synergy* varied from ~1 to 50 m (1 to 55 yd) in depth with a typical depth of 25 to 30 m (27 to 33 yd). A typical borehole took approximately 16 h to complete, from arrival on borehole target location through the retrieval of all coring gear, but was highly variable and dependent on gear performance and the substrates encountered.

The *Synergy* switched to dynamic positioning mode in preparation for coring upon arrival at a proposed borehole site. After completing any required positioning validation tests, the seabed frame and drill string was deployed to the sea floor. Coring and sampling commenced from the "mud line" to the target borehole depth. Upon reaching the targeted depth, the drill string and seabed frame were retrieved on board and the *Synergy* would either "bump over" to the next borehole site in dynamic positioning mode or transit with conventional propulsion to the next location.

Marine Mammal Monitoring

Vessel-based marine mammal monitoring and mitigation was conducted from the *Duke* and the *Synergy* throughout operations in the Chukchi Sea. Two MMOs were on duty during nearly all daylight periods on both vessels. During seismic activity on the *Duke*, two MMOs were on duty for all daytime ramp ups and at least one MMO was present for nighttime watches when airguns were active. On the *Synergy*, at least one MMO was on watch during all daylight hours, regardless of vessel activity, with one other MMO available for on-call assistance. During all periods of darkness aboard the *Synergy*, one MMO was available on-duty to performed periodic scans for marine mammals around the vessel. In addition, the lead MMO on the *Synergy* remained on call during nighttime to assist the on-duty MMOs. During daylight hours, scans were made with Fujinon 7×50 reticle binoculars, the unaided eye, and during excellent visibility conditions Fujinon 25×50 "Big-Eye" binoculars or Zeiss 20×60 image stabilized binoculars. During periods of darkness, MMOs frequently scanned areas around the vessel using generation 3 night vision goggles.

Chapter 4 provides a detailed description of the methods and equipment used for monitoring and mitigation during the site survey and geotechnical coring, as well as the data analysis methodology. Results of the marine mammal monitoring program are presented in Chapters 5 and 6.

Communication with Native Communities

While working in the Chukchi Sea, personnel contracted by Statoil (most often the MMOs) aboard the *Duke* and the *Synergy* routinely contacted the communication center (comm. center) in Wainwright which was jointly funded by Statoil and other industry operators. 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 12 hours. The current vessel location and activities were reported during each call. Additional contacts were made with the Wainwright comm. center on the three occasions when the *Duke* and *Synergy* went to Wainwright to complete personnel transfers. There were no reported conflicts encountered during the survey.

Prior to the survey season, numerous contacts and meeting were made with Native villages and subsistence organizations in an effort to understand and minimize any potential impacts on subsistence hunting activities. The meetings are summarized in Table 2.1.

TABLE 2.1. Meetings with Native communities, community leadership, and subsistence user groups before and after the 2011 open-water activities.

Month	***Dates***	***Year***	***Participation***	**Group/Location**
November	3-5	2010	Community Meeting	Kotzebue, Point Hope, Point Lay, Wainwright, and Barrow (with CPAI)
November	9-10	2010	Presentation	Beluga Whale Committee
November	9-10	2010	Attendance	Ice Seal Committee
December	8-9	2010	Presentation	4th Quarter AEWC Commissioner's Meeting
December	16	2010	Presentation	North Slope Borough Planning Commission
December	17	2010	Presentation	North Slope Borough Wildlife Department
February	18	2011	Presentation	AEWC Mini-Convention Conflict Avoidance Agreement, Barrow
March	7-8	2011	Presentation	Arctic Open Water Meeting
March	22	2011	Presentation	Plan of Cooperation Meeting - Point Hope
March	23	2011	Presentation	Plan of Cooperation Meeting - Point Lay
March	24	2011	Presentation	Plan of Cooperation Meeting - Wainwright
March	25	2011	Presentation	Plan of Cooperation Meeting - Barrow
March	29-31	2011	Attendance	North Slope Science Initiative Worship, Barrow
April	28	2011	Presentation	North Slope Borough Planning Commission
August	3-5	2011	Presentation	Arctic Economic Development Summit
October	*25*	*2011*	*Community Meeting* *****	*Point Lay*
October	26	2011	Community Meeting	Wainwright
October	27	2011	Community Meeting	Barrow
October	27	2011	Presentation	North Slope Borough Planning Commission
October	28	2011	Community Meeting	Atqasuk
November	7-10	2011	Community Meeting	Point Hope
November	*8*	*2011*	*Community Meeting* *****	*Kotzebue*
November	*9*	*2011*	*Community Meeting* *****	*Kivilina*
November	*10*	*2011*	*Community Meeting* *****	*Nome*
December	12-13	2011	Presentation	Quarterly AEWC Meeting
December	15	2011	Presentation	Northwest Arctic Leadership Team

* Cancelled due to weather or scheduling conflict; being resheduled for Jan/Feb 2012.

3. UNDERWATER SOUND MEASUREMENTS[1]

Introduction

Sound Source Measurements Overview

This chapter presents the results of two underwater acoustic studies designed to verify and characterize the sound emissions of vessels and equipment involved in Statoil USA E&P Inc.'s 2011 marine survey program in the Alaskan Chukchi Sea. The sound source measurement studies were performed by JASCO Applied Sciences to address the underwater noise monitoring requirements of Statoil's Incidental Harassment Authorization (IHA). The marine survey programs referred to in the IHA included the Shallow Hazards and Site Clearance survey, and the Geotechnical Soil Investigation program. The Shallow Hazards survey involved use of small airgun systems and sub-bottom profiling sonar to identify near-seafloor geological features that could impact drilling operations. The Geotechnical Soil Investigation program used single-beam and acoustic positioning sonar to assist the drilling of seabed core samples while the drillship was in dynamic positioning (DP).

Conditions 7(c), 9(a), and 9(b) of the IHA define the reporting requirements for sound source measurements (see excerpts in italics below). Field reports were delivered within five 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*
>
> *(b) Field Source Verification: Using a hydrophone system, the holder of this Authorization is required to conduct sound source verification tests for seismic airgun array, active acoustic sources, vessels that are involved in the surveys and geotechnical soil investigation, and underwater noise generated during these activities that include but are not limited to (A) vessels that are operating on dynamic positioning thruster, and (B) drilling noise from geotechnical soil investigation.*
>
> > *(i) Sound source verification shall consist of distances where broadside and endfire directions at which broadband received levels reach 190, 180, 170, 160, and 120 dB re 1 µPa (rms) for all active acoustic sources that may be used during the survey activities. For the airgun array, the configurations shall include at least the full array and the operation of a single source that will be used during power downs.*
> >
> > *(ii) The test results shall be reported to NMFS within 5 days of completing the test…*
>
> *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 Statoil's 2011 open*

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[1] By Graham Warner and Andrew McCrodan (JASCO Applied Sciences)

> *water shallow hazards surveys in the Chukchi Seas. The report will describe in detail: ... (iv)... Final and comprehensive reports to NMFS should summarize and plot: ... (B) The respective predicted received sound conditions over fairly large areas (tens of km) around operations...*

The Shallow Hazards and Geotechnical Soil Investigation programs' sound source measurements were conducted in the Alaskan Chukchi Sea in August and September of 2011, respectively. All measurements were made with calibrated sound recording equipment deployed to the seabed near each of the operations monitored. Two JASCO Ocean Bottom Hydrophone (OBH) systems and one JASCO Autonomous Multi-channel Acoustic Recorder (AMAR) system were deployed on the seabed to measure the sound sources. Low-frequency sources (< 24 kHz) were monitored with the OBH recorders while higher-frequency sources were monitored with the AMAR.

The sources measured for the Shallow Hazards program included: a 40 in^3 airgun array, 10 in^3 single mini-airgun, single-beam sonar, sub-bottom profiler, side-scan sonar, multibeam sonar, Ultra Short Baseline (USBL) acoustic positioning system, and M/V *Duke* survey vessel. Sources measured for the Geotechnical Soil Investigation program included: single-beam echosounder, High Precision Acoustic Positioning (HiPAP) 500 acoustic positioning system, and the M/V *Synergy* survey vessel in transit, in DP, and in DP while coring. 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 2011 airgun source measurements with past measurements of equal volume airgun sources performed for Shell Offshore Inc.'s Shallow Hazards programs in the Chukchi and Beaufort seas. 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 measurement programs included:

1. Establishing the distances from airgun array sources that root-mean-square (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 survey vessels.
2. Characterize the source spectra (1-Hz bands), 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 sonars operating above 180 kHz, investigate the spectral characteristics to determine if detectable sound emissions occurred below 180 kHz which might indicate their possible audibility to some marine mammals.
4. Measure source levels and distances to sound level thresholds from the vessels used for Statoil'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

Measurement Apparatus and Calibration

Underwater sound level measurements were obtained using two autonomous Ocean Bottom Hydrophone (OBH) recorder systems, and one Autonomous Multi-channel Acoustic Recorder (AMAR) system. The OBH units recorded two channels of acoustic data using two different hydrophones with different sensitivities (Fig. 3.1). The low sensitivity channel was recorded using a Reson TC4043 with nominal sensitivity -201 dB re V/µPa, and the high sensitivity channel was recorded using a Reson TC4032 with nominal sensitivity -170 dB re V/µPa. Each OBH recorded the hydrophone signals using a calibrated Sound Devices 722 24-bit audio hard-drive recorder sampled at 48 kilo-samples per second (ksps). The AMAR recorded one channel of high frequency acoustic data using a Reson TC4014 hydrophone with nominal sensitivity -186 dB re V/µPa. This AMAR recorded 16-bit samples at 687.5 ksps. Upon retrieval of the recorders, the data were transferred to external hard drives for backup. The recorders provided high-resolution, digital underwater sound recordings for the acoustic program.

The OBH systems were calibrated in the lab and immediately prior to deployment using a GRAS 42AC pistonphone calibrator. The pistonphone generates a precise 250-Hz reference tone at the hydrophone sensor that allows end-to-end recording system calibration to absolute pressure at the reference frequency.

The AMAR could not be calibrated with the pistonphone calibrator because the tapered design of the TC4014 sensing element cannot be inserted into a standard coupling. Its sensitivity was computed by adding the factory TC4014 calibration sensitivity (frequency-dependent) to the calibrated digitization gain of the AMAR electronics.

The OBHs and AMAR were fitted with floats and an acoustic release. Single 120 lb chain links were used as ballast to sink the recorders on deployment. Upon recovery, a coded signal was transmitted to trigger the acoustic release to drop the ballast. The recorders then floated to the surface and were retrieved using a mooring hook and crane. All but one of the ballast anchors were later retrieved using a grapple.

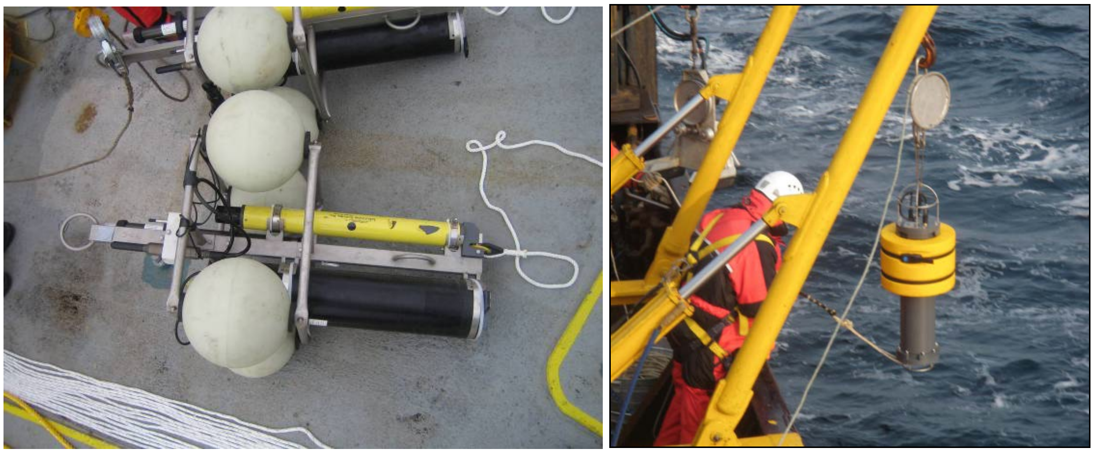


FIGURE 3.1. Photograph of a JASCO Ocean Bottom Hydrophone (OBH) recorder (left) and an Autonomous Multi-channel Acoustic Recorder (AMAR) system (right).

Field Measurement Procedures

Duke Test Procedure

Underwater acoustic measurements were conducted at a location on Statoil's exploration lease area in the Chukchi Sea, approximately 270 km (168 mi) west of Point Barrow (Fig. 3.2). Two OBHs and one AMAR recorder were deployed from the seismic vessel *Duke* to measure *in situ* sound pressure levels (SPL) versus distance from the sound sources.

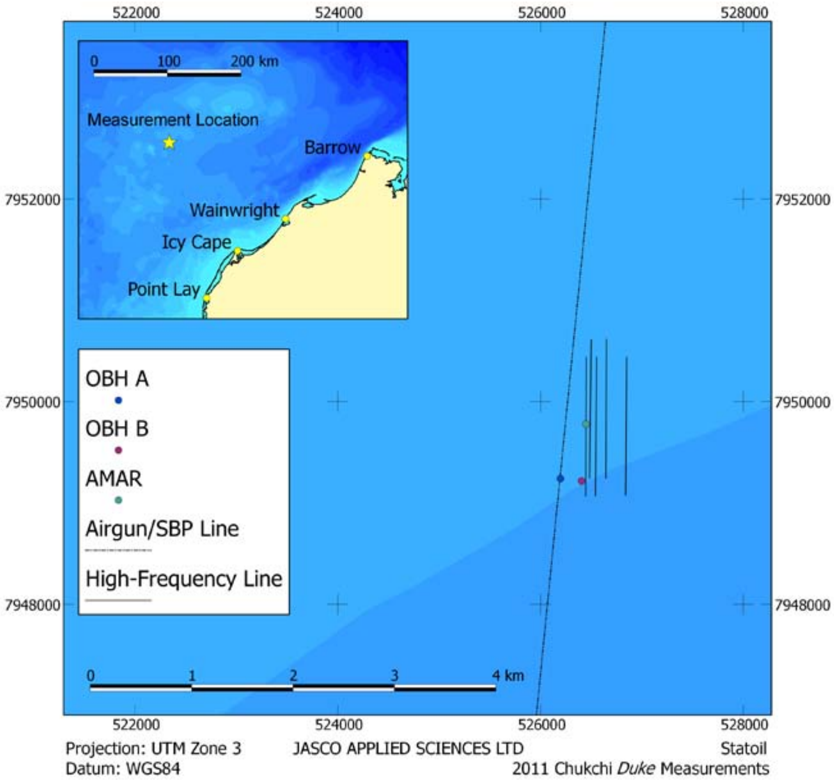


FIGURE 3.2. Map of Statoil's project area with the *Duke* track lines and recorder deployment locations.

Sound levels from the high frequency sonar sources were measured using the AMAR as the *Duke* transited along five 1 km (0.6 mi) long track lines. The sonar track lines were offset 0, 50, 100, 200, and 400 m (0, 55, 109, 219, 437 yd, respectively) from the AMAR (see Fig. 3.3).

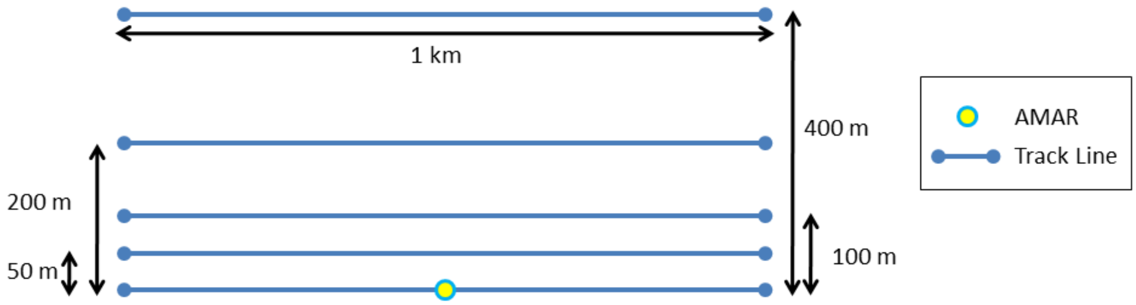


FIGURE 3.3. Track lines relative to the AMAR recorder for the high frequency source measurements.

Sound levels produced by signals from the 40 in³ airgun array, 10 in³ airgun, sub-bottom profiler, single-beam sonar, and vessel self-noise were measured using the OBH recorders as the *Duke* transited along a 25 km (16 mi) track line. The OBH deployment geometry allowed for the calculation of sound levels in the broadside (perpendicular to track line) and endfire (parallel to track line) directions. Fig. 3.4 shows the track layout for the low frequency source measurements.

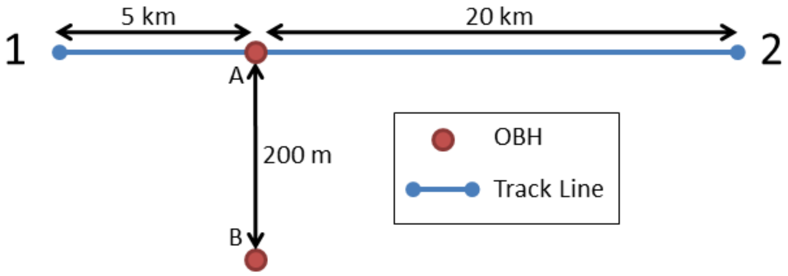


FIGURE 3.4. Track line relative to the OBH recorders for the low frequency source measurements.

The *Duke* transited from point 1 to 2 while operating the 40 in³ airgun array and transiting at its normal survey speed (4.5 kts). The *Duke* then turned around and operated the single 10 in³ airgun from point 2 to 1. The airguns fired every 12.5 m (13.7 yd) over ground (approximately 6 seconds). The airguns were then turned off and the sub-bottom profiler was operated while the *Duke* transited from point 1 to OBH A. At that point, the sub-bottom profiler was turned off and the *Duke* transited an additional 5 km (3 mi) for the vessel self-noise measurement.

Each OBH recorded approximately 22 hours of acoustic data. After completion of the test, the *Duke* recovered the OBHs and AMAR. Table 3.1 shows the start and end coordinates of each of the track lines.

Table 3.2 shows the OBH locations and deployment and retrieval times.

TABLE 3.1. GPS coordinates (WGS-84) and times of the track lines. All lines occur on 08 Aug 2011.

Track line	Start Time (UTC)	End Time (UTC)	Start Coordinates	End Coordinates
HF Line 5	08:53:01	09:03:51	71° 39.201’ N 165° 45.857’ W	71° 38.471’ N 165° 45.810’ W
HF Line 4	09:16:36	09:26:22	71° 38.563’ N 165° 45.480’ W	71° 39.299’ N 165° 45.521’ W
HF Line 3	09:42:47	09:52:41	71° 39.203’ N 165° 45.352’ W	71° 38.469’ N 165° 45.301’ W
HF Line 2	10:11:11	10:21:23	71° 38.563’ N 165° 45.208’ W	71° 39.297’ N 165° 45.264’ W
HF Line 1	10:39:07	10:49:08	71° 39.204’ N 165° 45.177’ W	71° 38.467’ N 165° 45.138’ W
40 in³ Line	12:40:30	15:54:55	71° 35.722’ N 165° 43.702’ W	71° 49.330’ N 165° 48.549’ W
10 in³ Line	17:48:39	21:03:11	71° 49.839’ N 165° 48.754’ W	71° 35.851’ N 165° 43.771’ W
SBP/Vessel Line	21:28:41	22:41:57	71° 35.978’ N 165° 43.818’ W	71° 41.267’ N 165° 45.689’ W

TABLE 3.2. OBH location coordinates (WGS-84) and deployment and retrieval times for the underwater acoustic measurements.

Recorder	Deployment Time (UTC)	Retrieval Time (UTC)	Latitude	Longitude	Water Depth (m)
OBH A (S-03)	05:34 8-Aug	00:41 9-Aug	71° 38.562' N	164° 15.283' W	37
OBH B (S-05)	06:24 8-Aug	00:52 9-Aug	71° 38.548' N	164° 14.929' W	37
High-Frequency AMAR (013)	05:07 8-Aug	00:03 9-Aug	71° 38.851' N	164° 14.845' W	37

Synergy Test Procedure

Underwater acoustic measurements were conducted at a location on Statoil’s exploration lease area in the Chukchi Sea, approximately 270 km (168 mi) west of Point Barrow (Fig. 3.5). Two OBHs and one AMAR recorder were deployed from the *Duke* to measure *in situ* SPLs versus distance from the sound sources. The *Duke* then departed the survey area and stationed 7-9 km (4-6 mi) to the north to avoid contaminating measurements of the *Synergy* and its sonar.

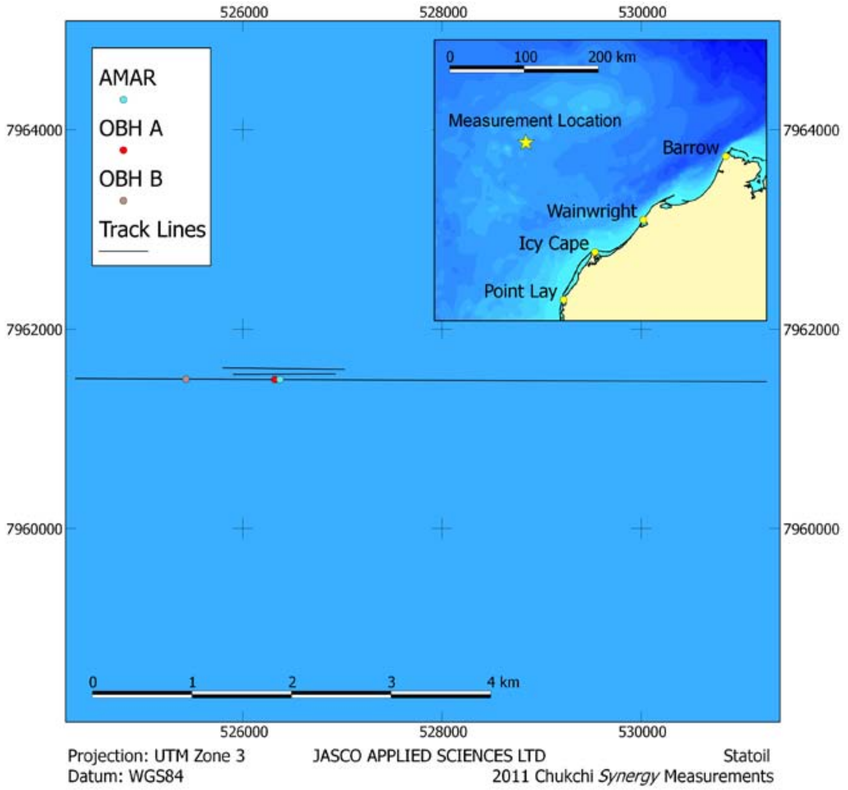


FIGURE 3.5. Map of Statoil's project area with the *Synergy* track lines and recorder deployment locations.

The *Synergy* conducted a series of three tests for these measurements. For the first test, the *Synergy* transited along three track lines at a speed of 4.5 kts while operating its sonar sources. The first track line was 7 km (4 mi) long and lay directly over the AMAR and OBH recorders; the second and third track lines were 1 km (0.6 mi) long, parallel to the first track line, and offset 50 and 100 m (55 and 109 yd) from the AMAR, respectively (Fig. 3.6). This test provided measurements of sound levels from the echosounders, HiPAP (operating at 22 and 23 kHz), and the *Synergy* itself. The following equipment was operating during the first test:

- port and starboard azipulls (azimuthal thrusters)
- 3 x diesel generators
- survey echosounders: 18 kHz and 200 kHz
- ship's fitted echosounder Furuno FE-700 (50 kHz)
- ship's Doppler log (1 MHz)
- HiPAP 500 operating at 22 and 23 kHz

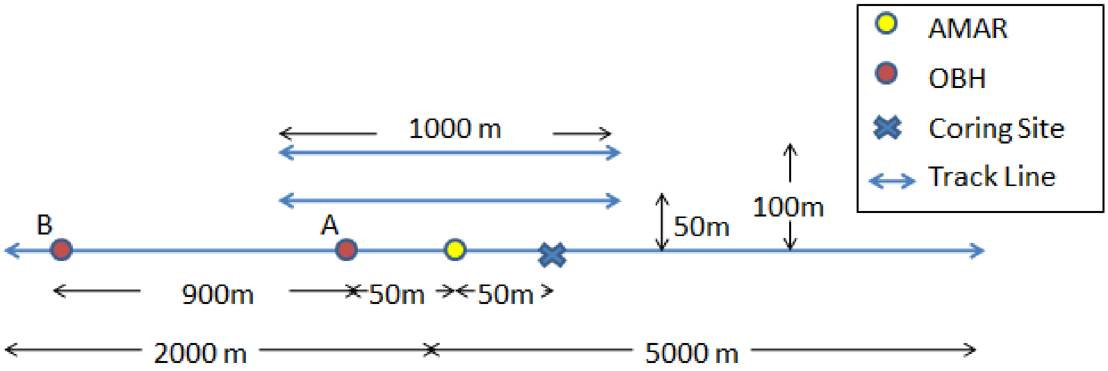


FIGURE 3.6. Track lines relative to the acoustic recorders and coring site.

After the first test, the *Synergy* moved to the coring site for the second test. The *Synergy's* second test was of the vessel in dynamic positioning (DP) mode without coring equipment operating. The second test began on 08-Sep-11 at 06:00:00 UTC. All other equipment was operational as per test 1. Test 2 concluded at 06:32:00 UTC.

The *Synergy's* third test was of the vessel in DP mode while coring operations were underway. Coring operations commenced on 09-Sep-11 at 08:55:00 UTC with the vessel in full DP mode and the coring equipment ready for deployment. The following equipment was operational for test 3:

- port and starboard azipulls
- 2 x forward tunnel thrusters
- forward retractable thruster
- 3 x diesel generator sets
- survey echosounders: 18 kHz and 200 kHz
- HIPAP 500 operating at 21 kHz and 21.5 kHz
- ship's echosounder Furuno FE-700 (50 kHz)
- ship's Doppler log (1 MHz)
- drilling tower hydraulic system
- top drive unit

Table 3.3 contains the sequence of operations versus timings for test 3. All times are in UTC. The HiPAP system on the seabed frame responded at 29 kHz, but was not in operation during the time period monitored by the AMAR which was the only recorder capable of recording sounds at that frequency.

TABLE 3.3. Coring operations sequence of events for 09 Sep 2011 aboard M/V *Fugro Synergy* for the third test.

Time (UTC)	*Event*
14:55:00	Commenced lowering Seabed frame
15:00:00	Seabed frame on the bottom
16:15:00	Drill pipe at mudline. Commence drill/sample/PCPT to 3m
18:10:00	PCPT at 3m on deck. Commence drill out.
18:23:00	Add joint of pipe
18:33:00	Continue drill out to 5m
18:37:00	Soil sampling at 5m
19:00:00	Commence drill out to 6m
19:10:00	PCPT at 6m
19:45:00	Commence pull drill pipe and seabed frame to moonpool
21:07:00	Seabed frame in the moonpool
21:25:00	Out of DP – commenced transit to "D" location

Each OBH recorded approximately 48 hours of acoustic data. The high frequency AMAR unit recorded approximately 26 hours of data. Table 3.4 depicts start and end locations of each of the track lines.

Table 3.5 shows the recorders' locations and deployment and retrieval times.

TABLE 3.4. Location coordinates (WGS-84) and times of the offset lines. All lines occur on 08 Sep 2011.

Track Line	Start Time (UTC)	End Time (UTC)	Start Coordinates	End Coordinates
0 m offset, 7 km line (E-W)	02:49:55	03:42:08	71.75174896° N 164.1057099° W	71.75285244° N 164.3041346° W
50 m offset, 1 km line (W-E)	04:06:11	04:13:40	71.75305206° N 164.2587956° W	71.75295259° N 164.2294433° W
100 m offset, 1 km line (E-W)	04:29:53	04:39:38	71.75337592° N 164.2266863° W	71.75364963° N 164.2617278° W

TABLE 3.5. OBH location coordinates (WGS-84) and deployment and retrieval times for the underwater acoustic measurements.

Recorder	Deployment Time (UTC)	Retrieval Time (UTC)	Latitude	Longitude	Water Depth (m)
High-Frequency AMAR (013) – 50 m from core	22:22 7-Sep	00:03 09-Sep	71.752533° N	164.245366° W	36.6
OBH A (S-05) – 100 m from core	22:56 7-Sep	00:52 09-Sep	71.752533° N	164.246833° W	36.6
OBH B (S-03) – 1000 m from core	23:34 7-Sep	00:41 09-Sep	71.752666° N	164.272366° W	36.4

Acoustic Metrics

By convention, underwater noise is measured in decibels (dB) relative to a fixed reference pressure of 1 μPa (equal to 10^{-6} Pa or 10^{-11} bar). Sound pressure levels (SPL) from impulsive noise sources are commonly characterized by three acoustic metrics: peak SPL, root-mean-square (rms) SPL, and sound exposure level (SEL). The standard equations for computing these metrics are provided below. All acoustic pressures in these formulas are in units of μPa.

The peak SPL (symbol L_{pk}) is the maximum instantaneous sound pressure level attained from a pressure pulse, $p(t)$:

Peak SPL: $$L_{pk} = 20\log_{10}(\max|p(t)|) \tag{1}$$

The rms SPL (symbol L_P) is the mean square pressure level integrated over a specified time window T containing the pressure pulse, $p(t)$:

rms SPL: $$L_P = 10\log_{10}\left(\frac{1}{T}\int_T p^2(t)\,dt\right) \tag{2}$$

When computing rms SPLs for airguns and other impulse noise sources, the time interval is generally taken to be the 90% energy pulse duration, and is represented by T_{90} (Malme et al., 1986; Greene 1997; McCauley et al., 1998). The 90% energy pulse duration for each seismic pulse is computed as the time window defined by the times corresponding to receipt of 5% and 95% of SEL. The rms SPLs computed in this way are consequently referred to as 90% rms SPLs (symbol L_{P90}). Because the window length acts as a divisor, pulses that are more spread out in time have a lower rms SPL for the same total SEL.

The SEL (symbol L_E) is a measure of the total sound energy contained in one or more pulses. SEL for a single pulse is computed from the time-integral of the squared pressure over a fixed time window, long enough to include the entire pulse:

SEL: $$L_E = 10\log_{10}\left(\frac{1}{T_{100}}\int_T p^2(t)\,dt\right) \tag{3}$$

SEL has units of dB re 1 $\mu\text{Pa}^2\cdot\text{s}$ and is a measure of sound exposure, rather than sound pressure. Species-specific SEL metrics may be computed by applying a frequency weighting filter to the pressure pulse data $p(t)$ in Equation (3) before computing the SEL, as discussed in the *Frequency M-Weighting* section below.

The cumulative SEL of a collection of N acoustic pulses is the sum of the SELs from the individual pulses:

Cumulative SEL: $$L_E(\text{cumulative}) = 10\log_{10}\left(\sum_{i=1}^{N} 10^{L_E^{(i)}/10}\right) \tag{4}$$

where $L_E^{(i)}$ is the SEL of the i^{th} pulse.

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:

90% rms SPL: $$L_{P90} = 10\log_{10}\left(\frac{1}{T_{90}}\int_{T_{90}} p^2(t)\,dt - \overline{n^2}\right) \tag{5}$$

SEL (in noise):
$$L_E^{(tot)} = 10\log_{10}\left(\int_T p^2(t)\,dt - \overline{n^2}T \right) \tag{6}$$

where $\overline{n^2}$ is the mean square pressure of the background noise, generally computed by averaging the squared pressure of a nearby segment of the acoustic recording during which pulses are absent (i.e., between pulses).

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}:

$$L_E = L_{P90} + 10\log(T_{90}) + 0.458 \tag{7}$$

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

Exposure Criteria and M-weighting

NMFS Criteria

Operational safety radii for the 2011 Statoil Shallow Hazards Program were based on rms auditory injury criteria developed by the National Marine Fisheries Service (NMFS). NMFS has defined two noise exposure criteria, corresponding to Level A harassment (auditory injury) and Level B harassment (behavioral disturbance) as defined in the US Marine Mammal Protection Act (see Richardson et al., 1995, §1.3). The NMFS criteria are based on the un-weighted rms SPL of single airgun pulses. The NMFS Level A criteria are based on estimates of marine mammal hearing damage thresholds extrapolated from known Damage Risk Criteria for humans (see discussion in Richardson et al., 1995, §10.5). The NMFS Level A criteria, intended to represent cautionary estimates for the onset of auditory system injury, are 190 dB re 1 µPa rms for pinnipeds and 180 dB re 1 µPa rms for cetaceans (e.g., US Federal Register 60:53753-60). The airgun array was to be powered down or shut down when marine mammal observers detected seals within the pre-defined 190 dB re 1 µPa safety radius and/or whales within the pre-defined 180 dB 1 µPa safety radius.

NMFS has also established a threshold criterion for behavioral responses (Level B harassment) to impulse noise sources. The threshold for the onset of behavioral response to seismic pulses is 160 dB re 1 µPa rms SPL, based on estimated received seismic noise levels during behavioral studies where baleen whales exhibited avoidance behavior around airgun pulses (e.g., Malme et al., 1984 and 1986). The airgun arrays were to be powered down or shut down when marine mammal observers detected aggregations of baleen whales (12 or more) within the ≥160 dB re 1 µPa rms zone. The NMFS behavioral threshold criterion was also used to estimate the number of animals potentially affected by the seismic survey.

Southall Auditory Injury Criteria

Recent literature suggests that frequency dependence of marine mammal hearing should be considered when establishing safety radii for seismic surveys. Based on a review of literature on marine mammal hearing and on physiological and behavioral responses to anthropogenic sound, Southall *et al.* (2007) have recently proposed alternative injury criteria for marine mammals, based on the peak SPL and SEL metrics. These criteria account for the type of sound (non-pulse, single-pulse, or multi-pulse), as well as the approximate hearing ranges of the mammals involved. The Southall injury criteria are for the onset of PTS (permanent threshold shift) in marine mammals. PTS is associated with unrecoverable hearing loss and auditory organ tissue damage. For a multi-pulse source such as an airgun array, Southall et al. have proposed the following injury criteria:

- Peak SPL: 230 and 218 dB re 1 µPa (unweighted) for cetaceans and pinnipeds, respectively
- SEL: 198 and 186 dB re 1 $\mu Pa^2 \cdot s$ (M-weighted) for cetaceans and pinnipeds, respectively

For a given situation, the more conservative of these two conditions should be applied. The Southall criteria were not mentioned in the Statoil IHA and these were not implemented to define exclusion zones. However, we have computed the Southall criteria metrics for the 40 in^3 and 10 in^3 track lines to provide a comparison with the rms criteria and for future reference.

Frequency M-Weighting

The M-weighting approach of Miller et al. (2005) is applied to account for the different hearing abilities of different marine mammals groups. It is similar to the C-weighting method that is used for assessing impacts of loud impulsive sounds on humans. M-weighting accounts for decreased hearing sensitivity above and below the most sensitive hearing range of marine mammals. Weighting curves are defined for five marine mammal groups: low-frequency cetaceans, mid-frequency cetaceans, high-frequency cetaceans, pinnipeds in air (not considered here), and pinnipeds underwater. The decibel weighting as a function of frequency, $W(f)$, is:

$$W(f) = -20\log_{10}\left(\frac{f^2 f_{hi}^2}{(f^2 + f_{lo}^2)(f^2 + f_{hi}^2)}\right) \tag{8}$$

where f_{hi} and f_{lo} are the estimated upper and lower hearing limits specific to each functional hearing group (Table 3.6). Fig. 3.7 shows the four underwater M-weighting curves as a f unction of frequency for each hearing group. M-weighted SELs are used for computing the Southall noise exposure criteria in a later section in this report.

Table 3.6. Functional marine mammal hearing groups and associated auditory bandwidths, as per Miller et al. (2005).

Functional hearing group	*Estimated auditory bandwidth*	
	f_{lo}	f_{hi}
Low-frequency cetaceans	7 Hz	22 kHz
Mid-frequency cetaceans	150 Hz	160 kHz
High-frequency cetaceans	200 Hz	180 kHz
Pinnipeds (underwater)	75 Hz	75 kHz

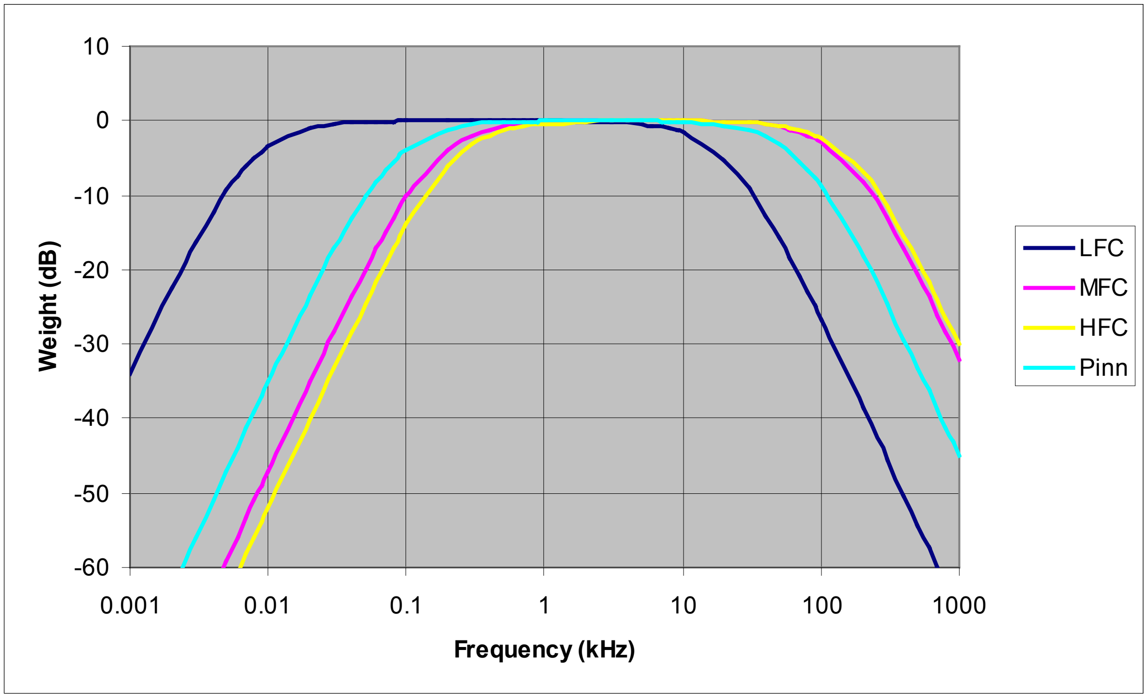


Figure 3.7. Decibel M-weighting versus frequency for underwater marine mammal functional hearing groups: low- (LFC), mid- (MFC), and high-frequency cetaceans (HFC), and pinnipeds underwater (Pinn).

Acoustic Signal Analysis Procedures

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. In some cases, apply a band-pass filter to isolate the targeted sound source from background noise and measurement artifacts (particularly for higher-frequency sonar).
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.

Sound Level versus Range

The noise metrics computed for each source are presented as a function of source-receiver range. The source-receiver range (and for the beam pattern calculation, angle) was calculated using the deployment coordinates of the recorder and the time-stamped GPS logs of the source. To estimate the distance to sound level thresholds, the 90% rms SPLs (L_{p90}) as a function of range (*R*, in meters) were fit with an empirical transmission loss function of the form:

$$L_{p90} = SL - n \log R - \alpha R, \text{ or} \tag{9}$$

$$L_{p90} = SL - n \log R \tag{10}$$

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 9 is used if absorptive losses are present or if apparent curvature exists in the received level versus log*R* data trend, whereas Equation 10 is used if no significant absorptive losses exist.

Sound Attenuation with Range

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. Source levels of the high frequency sources were calculated by back-propagating received levels using 20log*R* (spherical) spreading and α*R* attenuation. The attenuation coefficient, α, 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.

Cumulative SEL

The M-weighted cumulative SEL metric considers the total SEL received from multiple pulses and also accounts for frequency-dependent hearing sensitivity of different species groups. The auditory injury cumulative SEL threshold is 198 dB re 1 μPa^2-s (M-weighted) for cetaceans and 186 dB re 1 μPa^2-s (M-weighted) for pinnipeds under water.

The cumulative SEL metric proposed by Southall et al. involves summing the single pulse SELs for multiple pulses. They acknowledge that this approach is very conservative because it does not make any allowance for the recovery of hearing between pulse exposures. Their proposed cumulative SEL metric (flat weighted) is defined in Equation 4 above.

In the present study the cumulative SEL levels (both flat-weighted and M-weighted) were computed for all shots in a single seismic line. We computed these levels from data from both OBH recorders. It is important to note that if these levels were to be used for assessing impact then one would assume the exposed animals remained stationary throughout the exposure (while the airguns operated along the entire track line).

Spectral Analysis

The 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 was 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 *i*th standard pass-band is:

$$f_{ci} = 10^{i/10},\ \ i = 1, 2, 3, \ldots \qquad (11)$$

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

Shallow Hazards Seismic Survey (M/V Duke)

CTD Data

Temperature and sound velocity profiles of the water column at the *Duke's* measurement location were sampled before the *Duke's* test. The profiles were taken at 22:16 on 7 August 2011 (UTC) at 71°40.798'N 164°15.011'W. The water temperature and sound velocity profile obtained showed a well-mixed 16 m (17.5 yd) thick layer of warmer surface water (6° C, 43° F) above a deeper layer of cold water (–0.25° C, 31.5° F). This resulted in a two-layer sound velocity profile, with a transition from a higher velocity surface layer (1470 m/s, 1608 yd/s) to a lower velocity bottom layer (1444 m/s, 1579 yd/s) between 16 and 24 m (17.5 and 26 yd, respectively) depth. The sound velocity profile measured before the test is shown in Fig. 3.8. This profile, having higher sound velocity near the sea-surface, is downward-refracting.

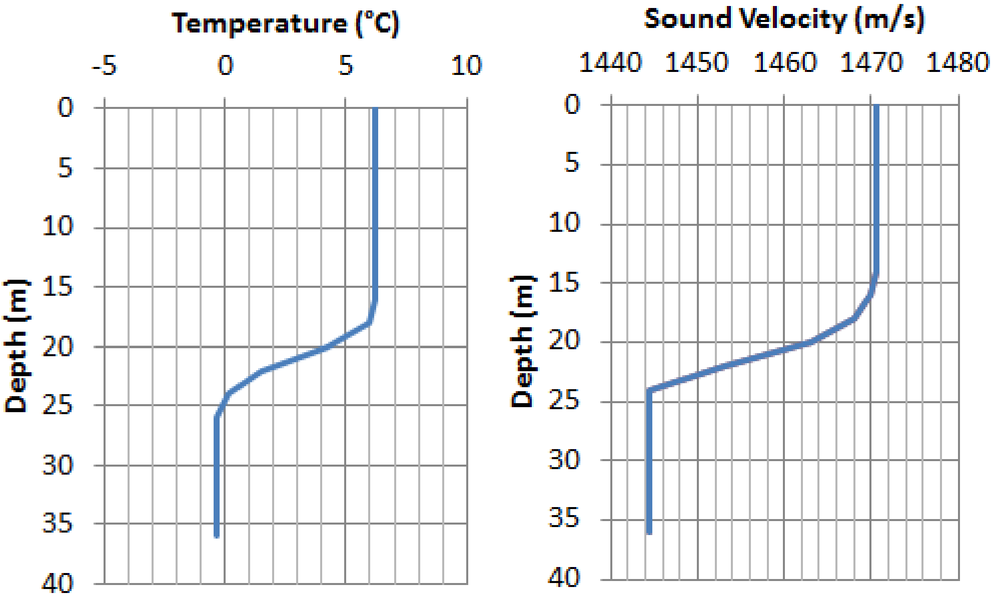


FIGURE 3.8. Measured ocean temperature profile and derived sound velocity profile from 22:16 on 7 August 2011 (UTC) at 71°40.798'N 164°15.011'W.

Airgun Array (40 in^3) Measurements

Peak SPL, 90% rms SPL and SEL for each shot were computed from acoustic data for OBH recorders A and B. The 40 in³ airgun array was fired every 12.5 m (14 yd) along the track line. Fig. 3.9 shows sound levels from the 40 in³ airgun array versus range. There was no difference between broadside and endfire levels so data from all directions relative to the array were combined for this analysis. Levels at distances less than 1 km (0.6 mi) are from the less sensitive TC4043 hydrophone; levels at distances greater than 1 km (0.6 mi) are from the more sensitive TC4032. Table 3.7 shows ranges to the 190 dB to 120 dB re 1 μPa rms SPL thresholds which were computed from the 90th percentile empirical curve fits to the SPL versus range data.

Fig. 3.10 presents spectrograms (plots of acoustic intensity versus time and frequency) of 40 in³ airgun array pulses measured on OBH A at 34 m (37 yd) closest point of approach (CPA), 2 km, 5 km, and 20 km (1, 3, and 12 mi, respectively). The spectrogram at 5 km (3 mi) range shows the time separation of the low frequency (below 20 Hz) ground refracted or head waves. This energy arrives in advance of the water borne pulse. Head waves and refracted waves propagate through the seabed where sound speeds are higher than in water. The airgun pulse duration is shown to increase with range due to modal dispersion of the sound energy, which can be most clearly seen in the 20 km (12 mi) figure. At least four modes are supported at this test location.

Fig. 3.11 shows a waveform and SEL spectral density plot of one pulse at 34 m 37 yd) slant range CPA. In the spectrum plot, background noise from a time window immediately preceding the pulse is plotted in red for comparison. Most of the array's energy occurs at frequencies below 1000 Hz.

Fig. 3.12 shows a contour plot of 1/3-octave band levels, versus range and frequency for the 40 in^3 array configuration. The contour plot shows the spectral distribution of sound energy measured on an OBH recorder, and also shows which frequencies dominated sound propagation at the test site. Sounds at frequencies between 100 and 300 Hz showed the strongest propagation with range; however, sound levels near the source were highest at frequencies between 30 and 200 Hz.

Equations of the form Equation 9 were fit to the peak levels in Fig. 3.9. The equations and distances to the Southall et al. (2007) proposed peak level thresholds are given in Table 3.8.

Cumulative SEL was calculated with respect to each OBH recorder. Each pulse was M-weighted before computing and summing SEL, providing cumulative SELs specific to low- (LFC), mid- (MFC), and high-frequency (HFC) cetaceans, and pinnipeds (PINN). The cumulative flat- and M-weighted SEL at each OBH are shown in Fig. 3.13. Flat-weighted per pulse SEL was included for comparison. In aggregate, these data indicate the cumulative SEL at fixed positions at various distances from the track line, increasing with the number of recorded pulses as the track line was traversed until the line flattens out where the weak pulses travelling over long ranges have little contribution. Note that if these levels were to be used for assessing impact then one would be assuming the exposed animals remained stationary throughout the exposure (while the airguns operated along the entire track line).

The total cumulative SEL for each hearing group is listed in Table 3.9. Fig. 3.14 shows the total cumulative SEL as a function of CPA distance. The total cumulative SEL did not reach the thresholds proposed by Southall et al. (2007) at the closest measured range. The distance to the injury criteria, if calculated using an equation of the form Equation 10, would be less than 1 m (1.1 yd) for all cetaceans and 6 m (6.5 yd) for pinnipeds. The peak level threshold distances (3 m [3.3 yd] for cetaceans and 11 m [12 yd] for pinnipeds) would therefore be used if the Southall injury criteria were followed.

Fig. 3.15 illustrates how rms pulse duration varied with range over the track line. The automatic pulse detector included energy from headwaves and reflected path arrivals, and the rms pulse duration was calculated from the resulting time windows (ref. steps 5 and 6 in Per-Shot Pulse Levels for how the pulse duration was calculated). At ranges greater than 150 m (164 yd), the pulse duration increased with range; however, at ranges less than 150 m (164 yd), pulse duration decreased with range. This change in the trend of pulse duration with range is explained in the discussion section.

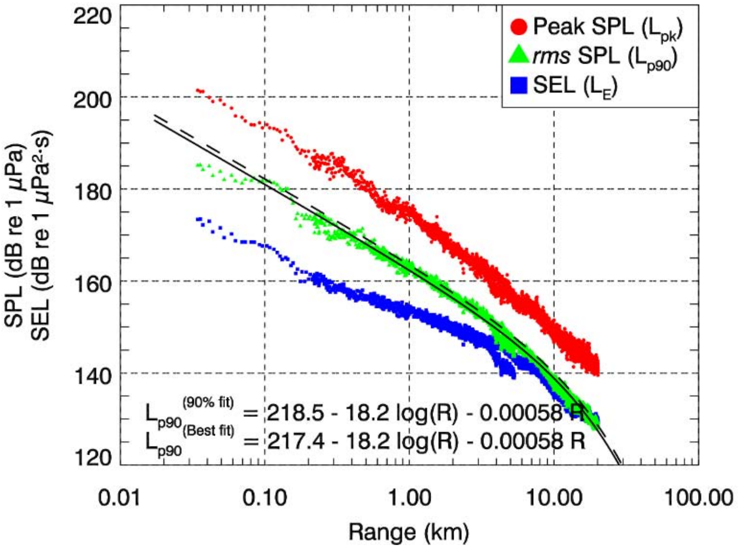


FIGURE 3.9. Peak SPL, rms SPL, and sound exposure level (SEL) versus slant range for 40 in^3 array airgun pulses at the measurement site. Solid line is best fit of the empirical function to SPL_{rms90} values. Dashed line is the best-fit adjusted to exceed 90% of the SPL_{rms90} values.

TABLE 3.7. Threshold radii for the 40 in^3 airgun array at the measurement site as determined from SPL_{rms90} versus distance data in Fig. 3.9.

SPL_{rms90} Threshold (dB re 1 μPa)	Best-Fit Line Radius (m)	90th Percentile Radius (m)
190	32	37
180	110	130
170	390	460
160	1300	1500
150	3900	4300
140	9200	10000
130	18000	19000
120	28000*	30000*

*Extrapolated beyond maximum measured range of 20 km.

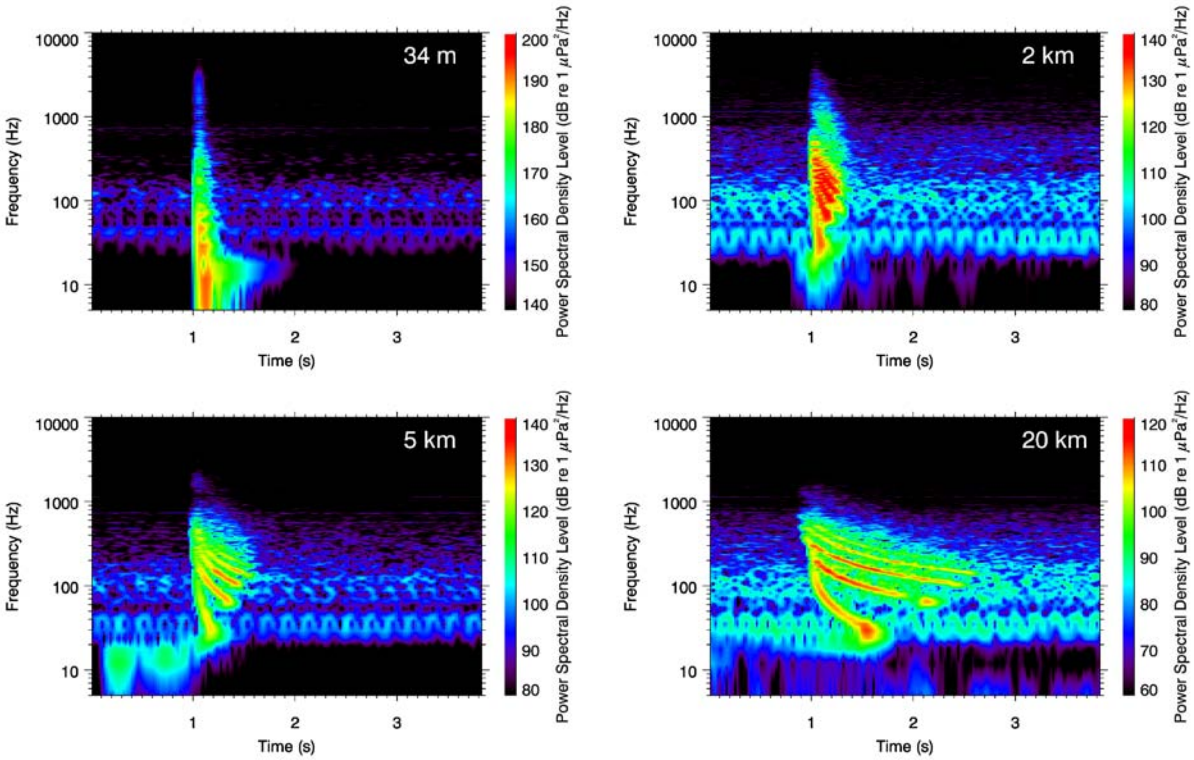


FIGURE 3.10. Spectrograms of 40 in³ airgun array pulses measured on OBH A. 48 ksps, 8192-pt FFT, 87.5% overlap, Hanning window.

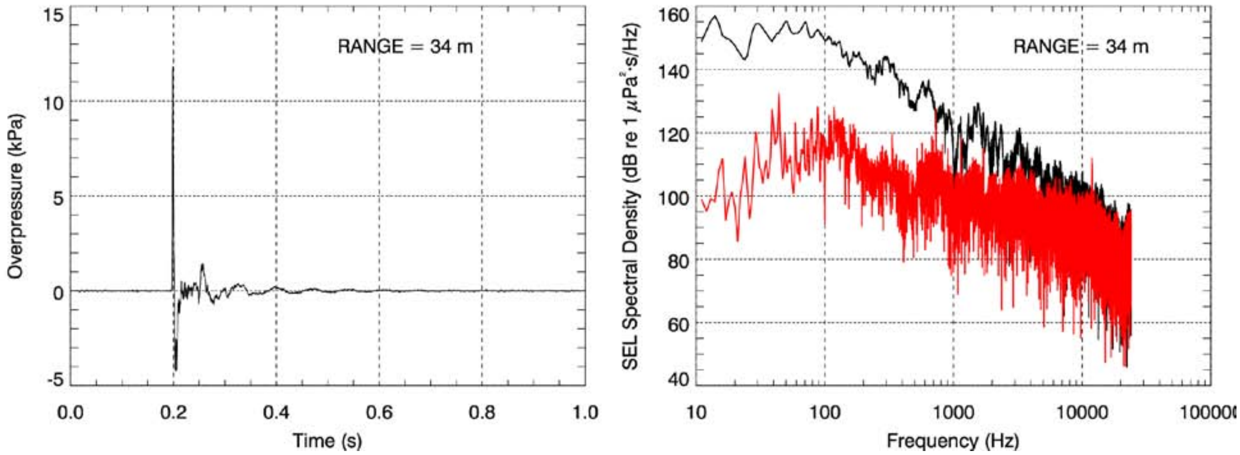


FIGURE 3.11. Waveform (left) and SEL spectral density plot (right) over 1 s of one 40 in^3 airgun pulse at 34 m (37 yd) slant range with background noise from the previous 1 s in red for comparison.

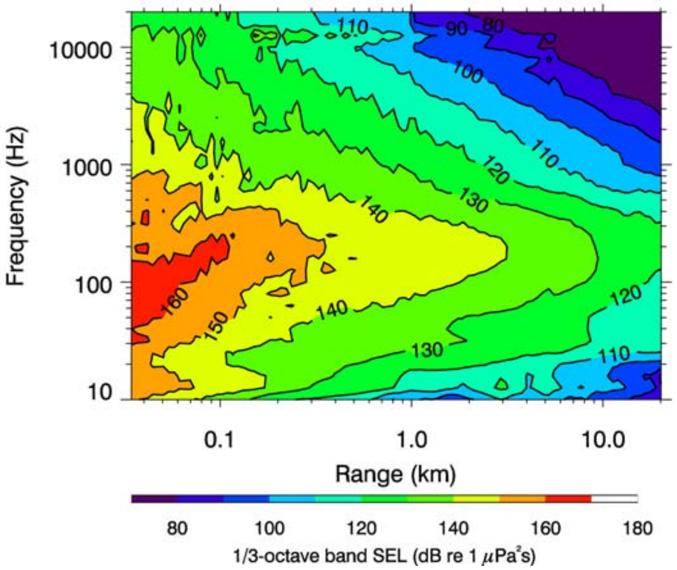
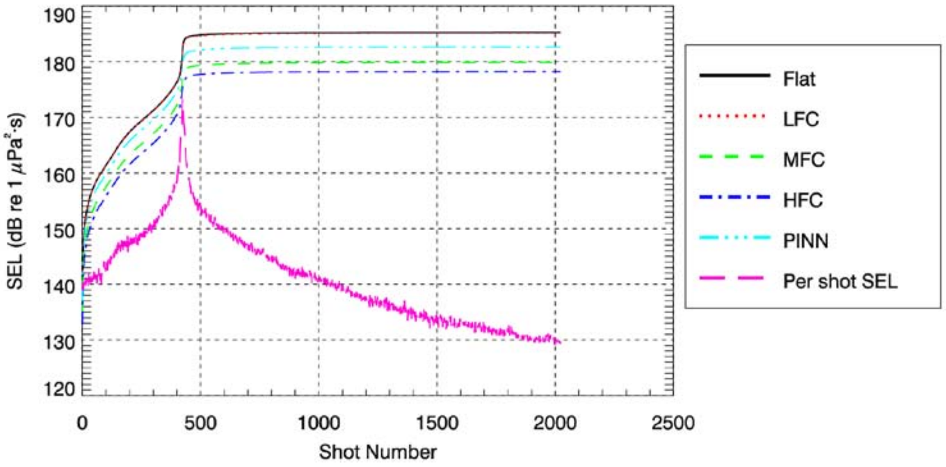


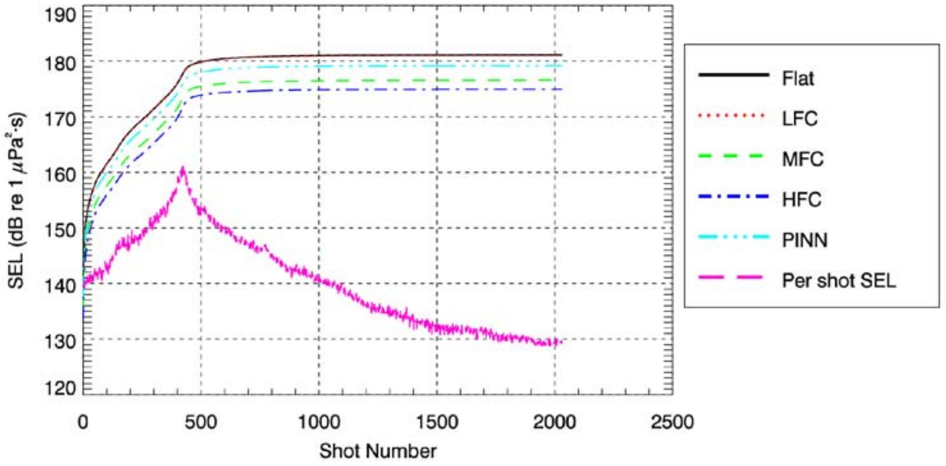
FIGURE 3.12. Third-octave band levels as a function of range and frequency for the 40 in^3 array configuration.

TABLE 3.8: Least squares best fit of Equation 9 to peak values (ref. Fig. 3.9) as well as distances to the Southall et al. proposed peak level threshold criteria. All distances are extrapolated from the minimum measurement range.

Array Configuration	Equation Type	Equation	Distance to 230 dB re 1 μPa (m)	Distance to 218 dB re 1 μPa (m)
40 in^3	Best fit	$L_{Pk} = 239.4 - 21.8 \log r - 0.00025 r$	3	10
	90th percentile	$L_{Pk} = 240.9 - 21.8 \log r - 0.00025 r$	3	11



(a)



(b)

FIGURE 3.13. Cumulative SEL: Flat- and M-weighted cumulative sound exposure level with flat-weighted per pulse SEL for OBH recorders (a) A and (b) B, with CPA distances of 34 and 220 m respectively. The 40 in^3 airgun array was fired every 12.5 m (14 yd).

TABLE 3.9. Total flat- and M-weighted cumulative sound exposure level (SEL) measured at fixed distances from the 40 in^3 track line.

	Total Cumulative SEL (dB re 1 μPa^{2}s)				
Distance at CPA	Flat-weighted	Low-frequency cetaceans	Mid-frequency cetaceans	High-frequency cetaceans	Pinnipeds Underwater
34 m	185.3	185.1	179.9	178.2	182.7
220 m	181.1	181.1	176.6	174.9	179.2

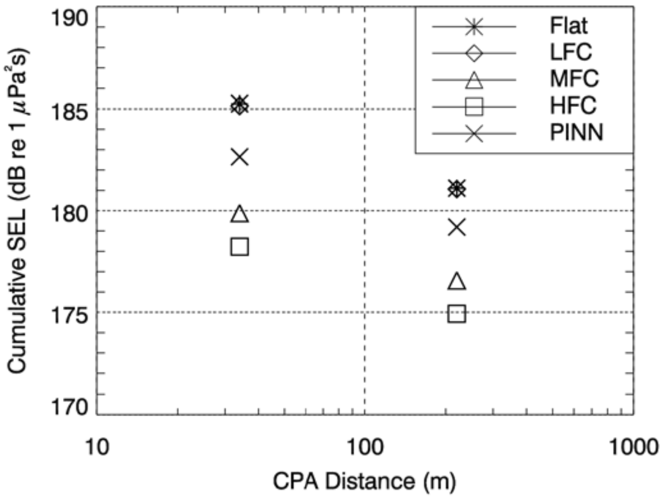


FIGURE 3.14. Cumulative SEL as a function of CPA distance for the 40 in^3 airgun array.

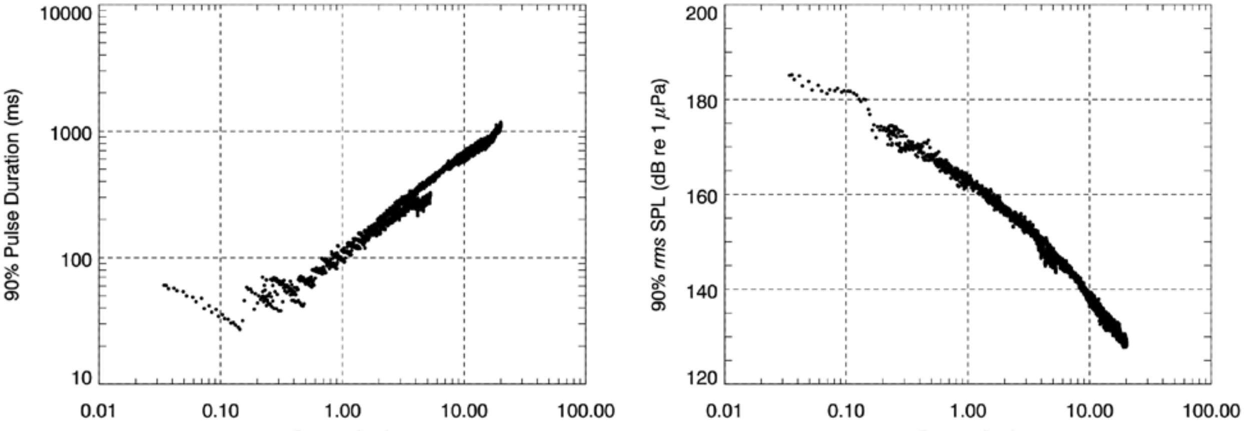


FIGURE 3.15. 40 in^3 airgun array 90% pulse duration and rms SPL as a function of range.

Mini-Airgun (10 in^3) Measurements

Peak SPL, 90% rms SPL and SEL for each mini-airgun shot were computed from acoustic data from OBHs A and B. The 10 in^3 mini-airgun was fired every 12.5 m(14 yd) along the track line, however, at CPA, problems with the mini-airgun required changing the shot spacing to 25 m (27 yd). Pulses received at less than 500 m (547 yd) slant range are from the less sensitive TC4043 hydrophone, and at greater than 500 m (547 yd) range are from the more sensitive TC4032. Fig. 3.16 shows sound level versus range data from the measurement site. Table 3.10 shows ranges to the 190 dB to 120 dB re 1 μPa rms SPL thresholds which were computed from the 90th percentile empirical curve fits to the SPL versus distance data.

Fig. 3.17 shows spectrograms of mini-airgun pulses measured at 38 m, 2 km, 5 km, and 21 km (41.5 yd, 1 mi, 3 mi, and 13 mi), respectively, CPA. The airgun pulse duration is shown to increase with range, and modal dispersion is apparent in the 5 km and 21 km (3 and 13 mi, respectively) spectrograms, supporting at least 3 modes. Unlike the 40 in^3 airgun array, head waves are not readily apparent.

Fig. 3.18 shows the waveform and SEL spectral density of a mini-airgun pulse at 38 m (41.5 yd) slant range over 1 s, with the previous 1 s of background noise plotted in red for comparison. The majority of the airgun pulse's energy occurs below 1000 Hz.

Fig. 3.19 shows a contour plot of 1/3-octave band levels vs. range and frequency. This plot shows the spectral distribution of pulses at increasing ranges, and identifies which frequencies dominate the propagation. For the mini-airgun in this location, frequencies between 30 and 300 Hz traveled the farthest, while at close-range the dominant range was 20 to 100 Hz. The small spike visible at 12 kHz is due to energy from the single-beam sonar.

Equations of the form Equation 9 were fit to the peak levels in Fig. 3.16. The equations and distances to the Southall et al. (2007) proposed peak level thresholds for the mini-airgun are given in Table 3.11.

Cumulative SEL for the mini-airgun line was calculated with respect to each OBH, and the results are shown in Fig. 3.20. Each pulse was M-weighted before computing and summing SEL, providing cumulative SELs specific to low- (LFC), mid- (MFC), and high-frequency (HFC) cetaceans, and pinnipeds (PINN). Flat-weighted per pulse SEL was included for comparison. Note that if these levels were to be used for assessing impact then one would be assuming the exposed animals remained stationary throughout the exposure (while the airguns operated along the entire track line).

Total cumulative SEL along the mini-airgun line for each group is presented in Table 3.12. If the mini-airgun continued firing every 12.5 m (14 yd) after CPA, the cSEL levels would be a few decibels higher. Fig. 3.21 shows the total cumulative SEL as a function of CPA distance. The total cumulative SEL did not reach the thresholds proposed by Southall et al. (2007) at the closest measured range. The distance to the injury criteria, if calculated using an equation of the form Equation 10, would be less than 1 m (1.1 yd) for all hearing groups. The peak level threshold distances (1 m [1.1 yd] for cetaceans and 2 m [2.2 yd]for pinnipeds) would therefore be used if the Southall injury criteria were followed.

Fig. 3.22 shows rms pulse length vs. range for the mini-airgun line, with rms SPL for comparison. The automatic pulse detector includes energy from refracted and reflected path arrivals, and uses the resulting time windows to calculate the rms pulse length. The pulse duration generally increases with range, except from 100 to 500 m (109 to 219 yd), where it decreases.

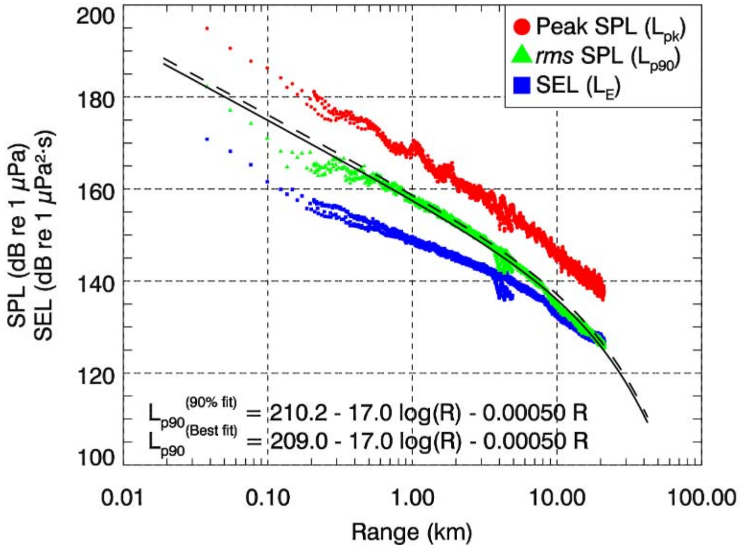


FIGURE 3.16. Peak SPL, rms SPL, and sound exposure level (SEL) versus slant range for 10 in^3 mini-airgun pulses at the measurement site. Solid line is best fit of the empirical function to SPL$_{rms90}$ values. Dashed line is the best-fit adjusted to exceed 90% of the SPL$_{rms90}$ values.

TABLE 3.10. Threshold radii for the 10 in^3 mini-airgun at the measurement site as determined from SPL$_{rms90}$ versus distance data in Fig. 3.16.

SPL$_{rms90}$ Threshold (dB re 1 µPa)	Best-Fit Line Radius (m)	90th Percentile Radius (m)
190	13*	15*
180	50	59
170	200	230
160	720	840
150	2500	2800
140	7000	7800
130	15000	17000
120	27000*	29000*

*Extrapolated beyond minimum measured range of 38 m.

*Extrapolated beyond maximum measured range of 20 km.

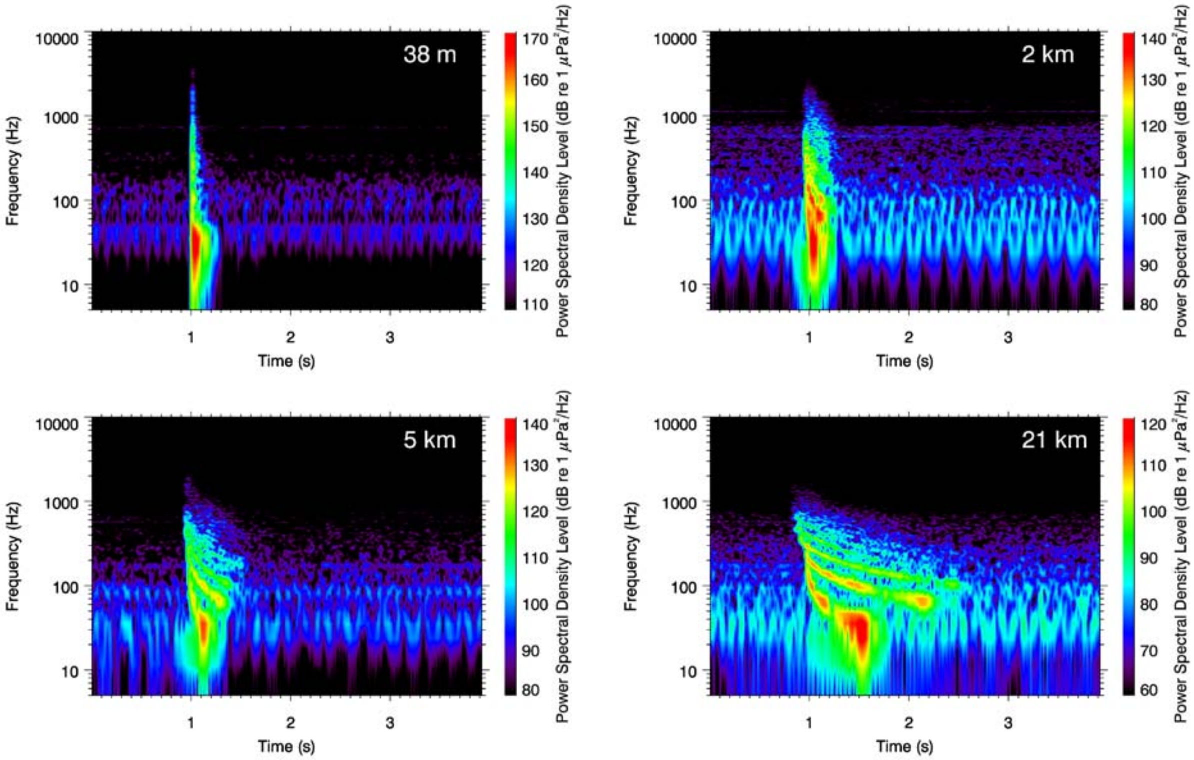


FIGURE 3.17: Spectrograms of 10 in³ airgun array pulses measured on OBH A. 48 ksps, 4096-pt FFT, 87.5% overlap, Hanning window.

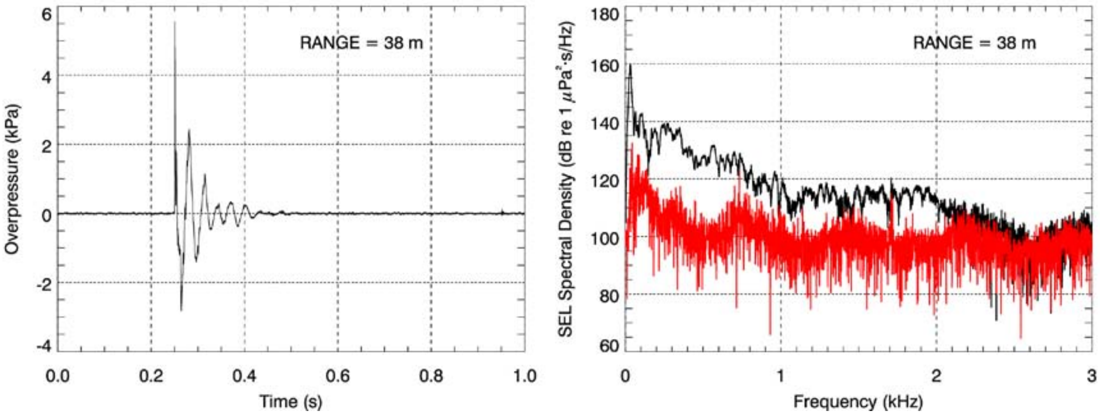


FIGURE 3.18. Waveform (left) and SEL spectral density plot (right) over 1 s of one mini-airgun pulse at 38 m (37 yd) slant range with background noise from the previous 1 s in red for comparison.

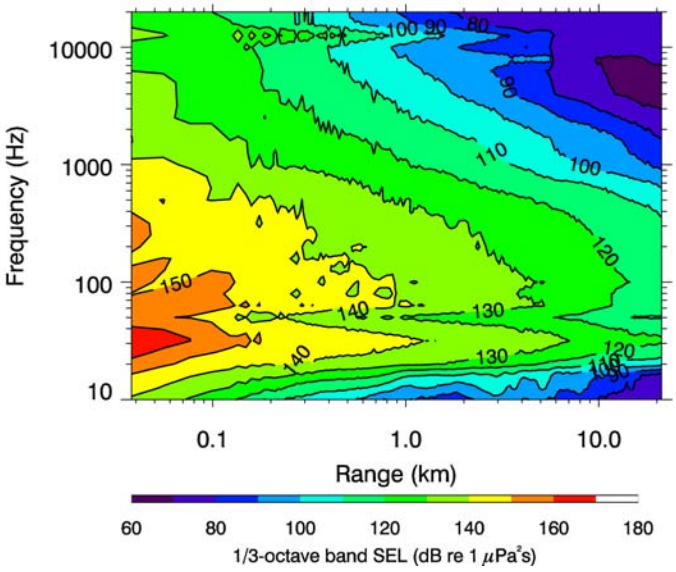


FIGURE 3.19. Third-octave band levels as a function of range and frequency for the 10 in^3 mini-airgun.

TABLE 3.11. Least squares best fit of Equation 9 to peak values (ref. Fig. 3.16) as well as distances to the Southall et al. proposed peak level threshold criteria. All distances are extrapolated from the minimum measurement range.

Array Configuration	Equation Type	Equation	Distance to 230 dB re 1 µPa (m)	Distance to 218 dB re 1 µPa (m)
10 in^3	Best fit	$L_{Pk} = 223.9 - 18.7\log r - 0.00028r$	<1	2
	90th percentile	$L_{Pk} = 225.4 - 18.7\log r - 0.00028r$	1	2

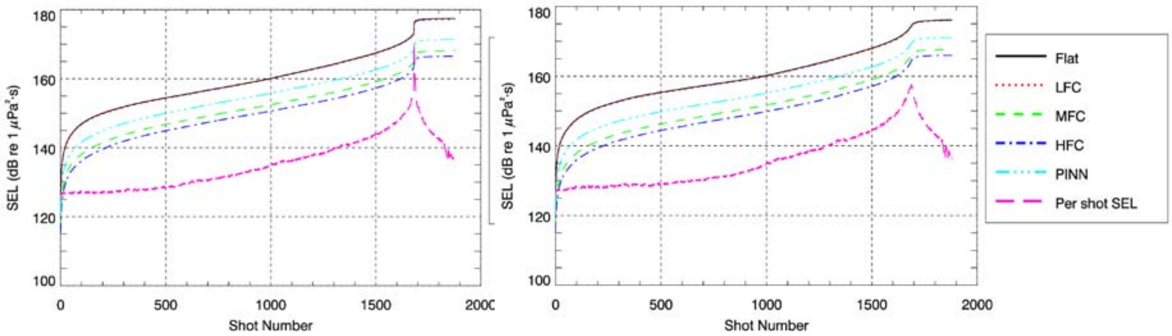


FIGURE 3.20. Cumulative SEL: Flat- and M-weighted cumulative sound exposure level with flat-weighted per pulse SEL for OBH recorders A (left) and B (right), with CPA distances of 38 and 209 m (41.5 and 229 yd) respectively. The mini-airgun was fired every 12.5 and 25 m (14 and 27 yd) before and after CPA, respectively.

TABLE 3.12. Total flat- and M-weighted cumulative sound exposure level (SEL) measured at fixed distances from the 10 in^3 mini-airgun track line.

Distance at CPA	Total Cumulative SEL (dB re 1 µPa^{2}s)				
	Flat-weighted	Low-frequency cetaceans	Mid-frequency cetaceans	High-frequency cetaceans	Pinnipeds Underwater
38 m	177.5	177.2	168.1	166.5	171.4
209 m	176.1	175.9	167.7	166.0	171.0

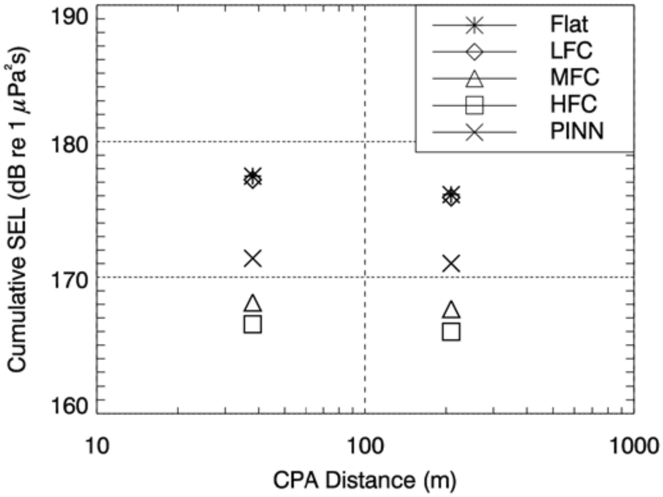


FIGURE 3.21. Cumulative SEL as a function of CPA distance for the 10 in³ mini-airgun array.

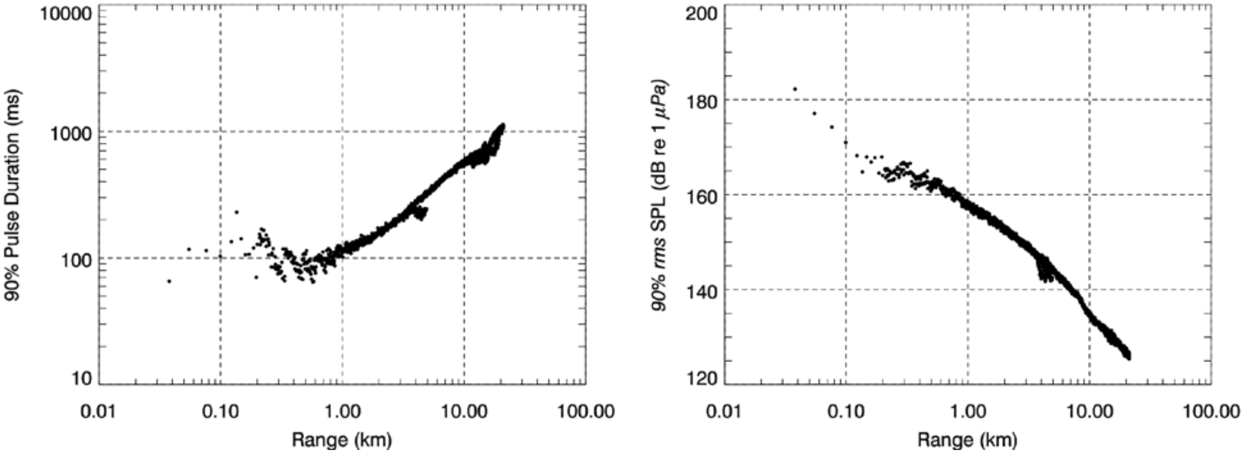


FIGURE 3.22. 10 in³ mini-airgun 90% pulse duration and rms SPL as a function of range.

Simrad EA502 Single-Beam Sonar Measurements

Peak SPL, 90% rms SPL and SEL for each single-beam sonar pulse were computed from acoustic data from OBHs A and B, filtered between 10 and 14 kHz. The more sensitive TC4032 hydrophone was used for all pulses except at very close range where peak levels exceeded 170 dB re 1 µPa to avoid clipping and non-linearity of response at high levels. For these close-range pulses the TC4043 was used. Single-beam sonar pulses occurred once every 3 seconds. Received levels were about 10 dB higher for the approach, suggesting that the sonar may be slightly forward-facing or the *Duke*'s hull shielded direct path propagation. Fig. 3.23 shows sound level versus range data from the measurement site. The sharp upward trend at close range represents pulses received from the main beam of the sonar, while the empirical fit functions more closely follow out-of-beam measurements. The fit function for the Simrad EA502 was used to determine the radii corresponding to threshold radii for levels below 160 dB re 1 µPa rms. This approach was chosen because the main beam is directed straight down under the vessel so would not be responsible for producing sound levels that exceed the thresholds at greater horizontal distances. The in-beam source level for the single beam sonar, computed by spherical scaling of the measurement of 188.5 dB re 1 µPa rms made at 29.8 m (32.5 yd), is 218.0 dB re 1 µPa rms. Table 3.13 shows ranges to the 150 dB to 110 dB re 1 µPa rms SPL thresholds which were computed from the 90th percentile empirical curve fits to the SPL versus distance data.

Fig. 3.24 shows a waveform and SEL spectral density plot of one pulse at 30 m (33 yd) slant range. In the spectrum plot, background noise from a time window immediately preceding the pulse is plotted in red for comparison. The main pulse is visible at 12 kHz, while part of a harmonic can be seen at the Nyquist frequency (24 kHz). Fig. 3.25 shows a spectrogram of one single-beam sonar pulse at CPA. The faint trail represents a reflection of the initial direct pulse.

Fig. 3.26 shows the vertical source level beam pattern of the single-beam sonar. The rms SPL of each pulse was back-propagated using 20log*R* (spherical) spreading and estimated absorption loss at the pulse center frequency (Francois and Garrison 1982: see methods section Sound Attenuation with Range), and the vertical angle at which each pulse was received. Since the source only emitted a pulse every three seconds, the beam pattern is not well resolved near 0°. However, it is still clear that there is primarily a vertical beam since source levels were highest near vertical.

Fig. 3.27 shows 1/3 octave band levels calculated from the average of the six highest-rms amplitude pulses around CPA, over 50 ms, with the average background noise from the 50-ms windows preceding each pulse plotted in red for comparison. The single-beam sonar pulses exceed background levels in the bands centered between 7.9 and 20 kHz, with the greatest excess contained in the 12.6-kHz band.

Third-octave band source levels were estimated by back-propagation of filtered levels assuming 20log*R* (spherical) spreading and estimated absorption loss at the 1/3-octave band center frequencies (Francois and Garrison 1982: see methods section Sound Attenuation with Range). The source levels for the bands centered at 7.9, 10, 12.6, 15.8, and 20 kHz are 150.3, 166.0, 192.6, 156.4, and 150.5 dB re 1 $\mu Pa^2 s$ at 1 m, respectively.

Fig. 3.28 shows rms pulse length vs. range for the single-beam sonar, with rms SPL for comparison. The pulse duration generally increases with range, and the in-beam direct-path pulses are significantly shorter than the out-of-beam measurements.

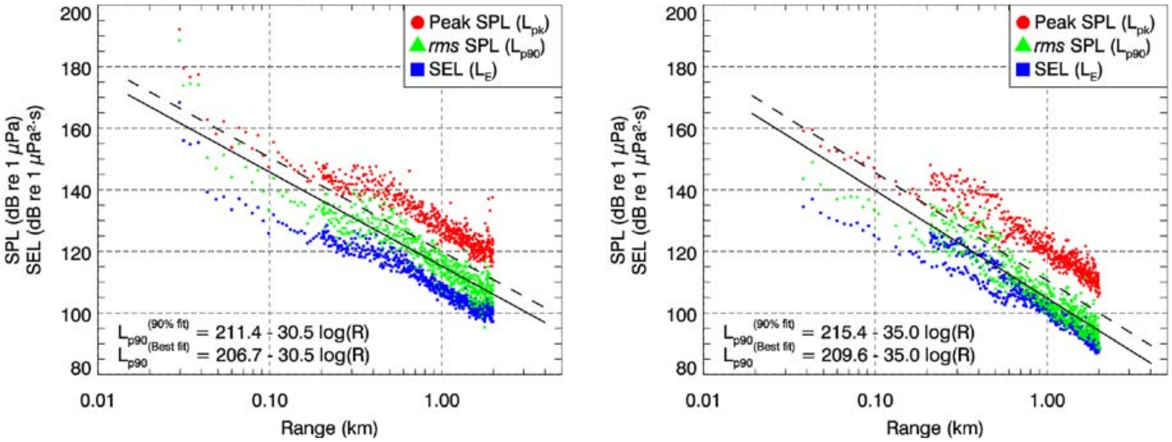


FIGURE 3.23. Simrad EA502 single-beam sonar peak SPL, rms SPL, and sound exposure level (SEL) versus slant range measured as the *Duke* approached (left) and departed (right) the OBH recorders. Solid line is best fit of the empirical function to $\mathrm{SPL}_{\mathrm{rms90}}$ values. Dashed line is the best-fit adjusted to exceed 90% of the $\mathrm{SPL}_{\mathrm{rms90}}$ values. Acoustic data were band-pass filtered between 10 and 14 kHz before calculating sound levels.

TABLE 3.13. Simrad EA502 single-beam sonar threshold radii at the measurement site as determined from $\mathrm{SPL}_{\mathrm{rms90}}$ versus distance data in Fig. 3.23.

$\mathrm{SPL}_{\mathrm{rms90}}$ Threshold (dB re 1 μPa)	Approach		Departure	
	Best-Fit Line Radius (m)	90th Percentile Radius (m)	Best-Fit Line Radius (m)	90th Percentile Radius (m)
170	-	38*	-	-
160	-	40*	-	-
150	72	104	51	74
140	150	220	98	140
130	330	470	190	280
120	700	1000	370	540
110	1500	2100**	710	1000

*Actual maximum slant range that the threshold was exceeded. Not from fit function.

**Extrapolated beyond maximum measured range of 2 km.

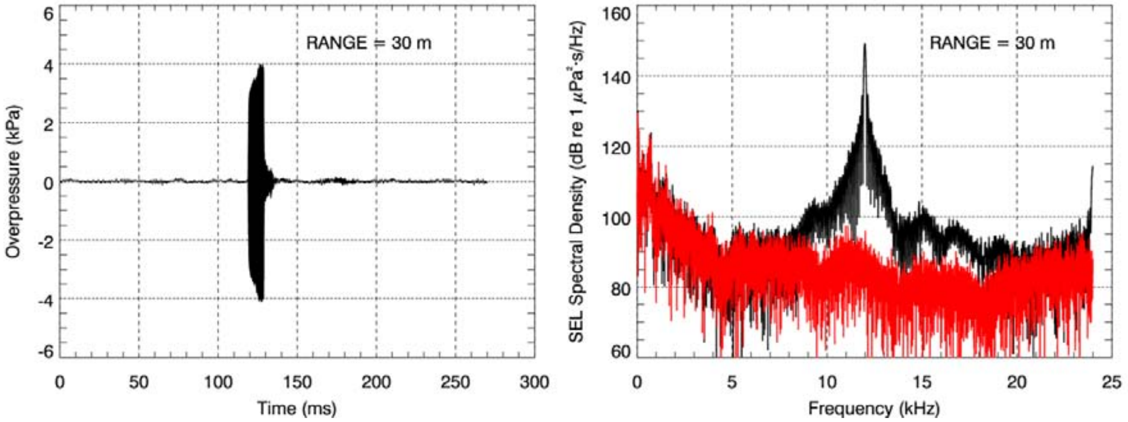


FIGURE 3.24. Simrad EA502 single-beam sonar waveform (left) and SEL spectral density plot (right) over 300 ms of one 12-kHz pulse at 30 m (33 yd) slant range with background noise from the previous 300 ms in red for comparison.

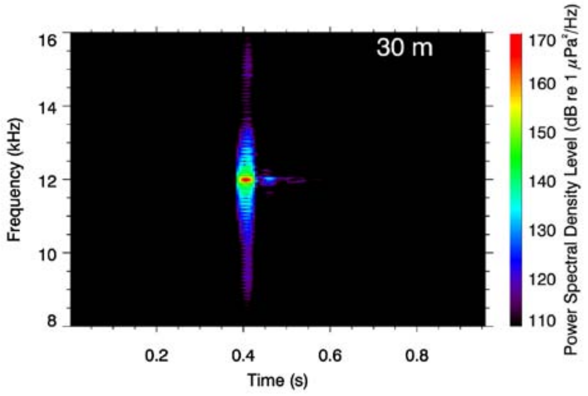


FIGURE 3.25. Simrad EA502 single-beam sonar spectrogram of one 12-kHz pulse measured on OBH A at 30 m slant range. 48 ksps, 2048-pt FFT, 87.5% overlap, Hanning window.

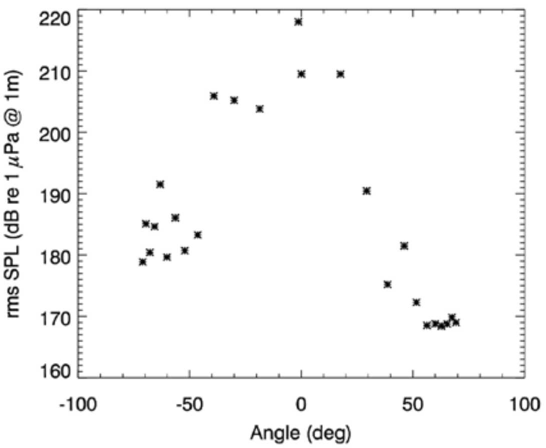


FIGURE 3.26. Simrad EA502 single-beam sonar rms SPL source level versus angle off vertical (straight down) measured as the *Duke* sailed directly over the recorder.

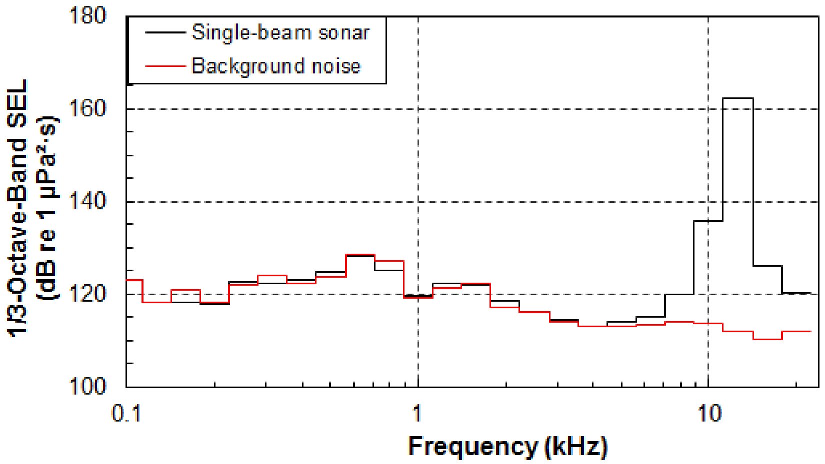


FIGURE 3.27. Simrad EA502 single-beam sonar 1/3-octave band SEL over a 50-ms time window. Data were averaged from the six highest-amplitude pulses, measured at 30 – 40 m (33 – 44 yd) slant range. The corresponding average band levels of background noise from the six preceding 50-ms windows are shown in red.

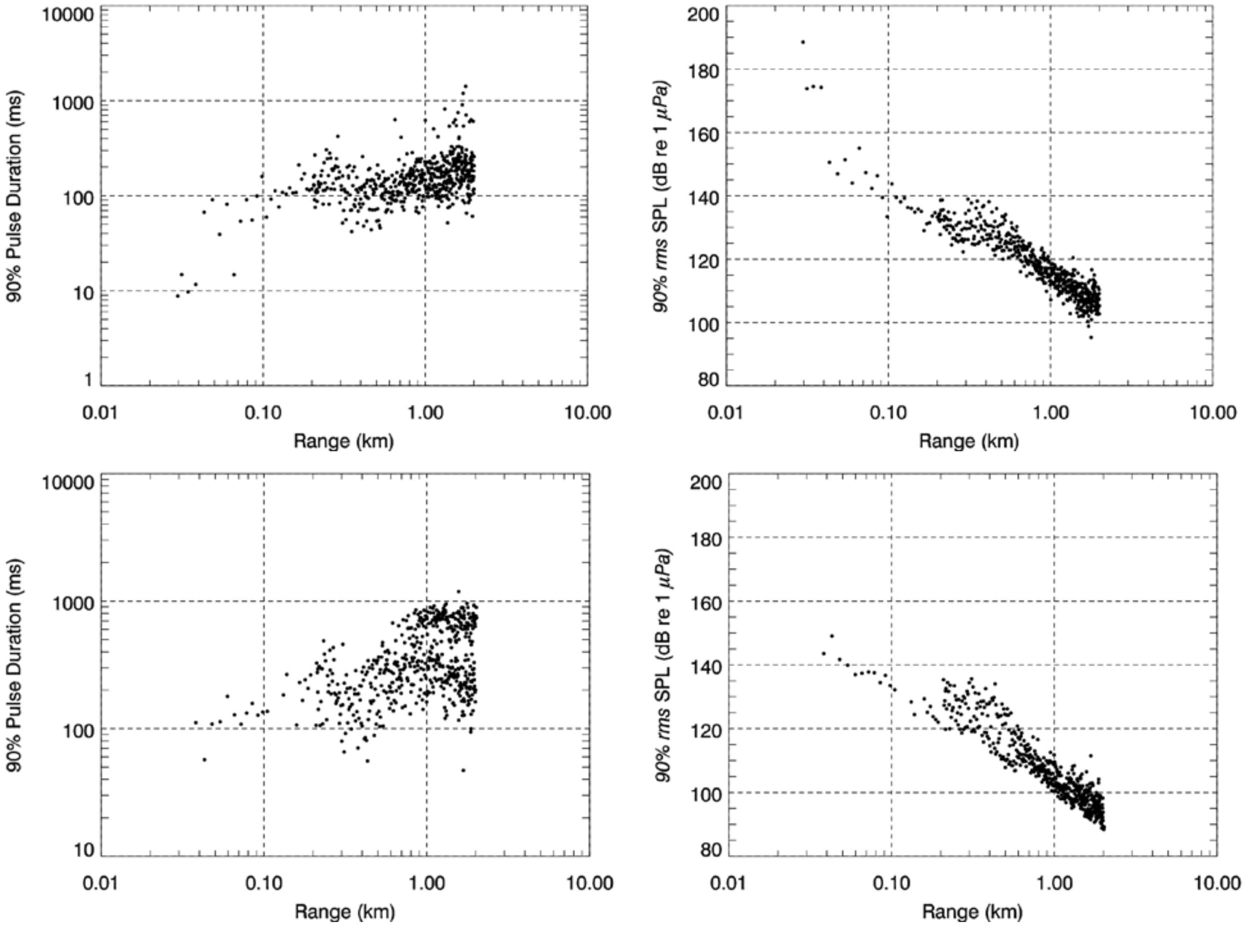


FIGURE 3.28. Simrad EA502 single-beam sonar 90% pulse duration and rms SPL as a function of range in the fore (top) and aft (bottom) directions. Single-beam pulses occurred once every 3 seconds.

Kongsberg SBP300 Sub-Bottom Profiler Measurements

Peak SPL, 90% rms SPL and SEL for each sub-bottom profiler pulse were computed from acoustic data recorded by OBH A, filtered between 1 and 10 kHz. Sub-bottom profiler pulses occurred once every 0.28 seconds. Fig. 3.29 shows sound level versus range data from the measurement site. The sharp upwards trend at close range represents pulses received from the main beam of the source, while the empirical fit functions more closely follow out-of-beam measurements. The fit function for the Kongsberg SBP300 measurements was used to determine the radii corresponding to threshold radii for levels below 150 dB re 1 μPa rms. This approach was chosen because the main beam of the sub-bottom profiler is directed straight down under its transducer so would not be responsible for producing sound levels that exceed the thresholds at greater horizontal distances. The in-beam source level for this sub-bottom profiler, computed by spherical scaling of the measurement of 166.4 dB re 1 μPa rms made at 29.7 m, is 195.9 dB re 1 μPa rms. Table 3.14 shows ranges to thresholds from 140 dB to 110 dB re 1 μPa rms SPL thresholds which were computed from the 90th percentile empirical curve fits to the SPL versus distance data.

Fig. 3.30 shows a waveform and SEL spectral density plot of one pulse at 30 m (33 yd) slant range. In the spectrum plot, background noise from a time window immediately preceding the pulse is plotted in red for comparison. The swept pulse is visible between 2 and 7 kHz. Fig. 3.31 shows a spectrogram of three sub-bottom profiler pulses around CPA. A reflection of each pulse is visible after the prominent direct-path signature.

Fig. 3.32 shows the vertical source level beam pattern from measurements as the sub-bottom profiler passed over the OBH. The rms SPL of each pulse was back-propagated using 20log*R* (spherical) spreading and estimated absorption loss at the pulse center frequency (Francois and Garrison 1982: see methods section Sound Attenuation with Range), and the angle at which each was received. Source levels were highest for near-vertical propagation. The primary beam was limited to ±20° off vertical.

Fig. 3.33 shows 1/3 octave band levels calculated from the average of the three highest-rms amplitude pulses around CPA, over 30 ms, with the average background noise from the 30-ms windows preceding each pulse plotted in red for comparison. The sub-bottom profiler pulses exceed background levels in bands centered between 3.2 and 6.3 kHz.

Third-octave band source levels were estimated by back-propagation of filtered (1–10 kHz) levels assuming 20log*R* (spherical) spreading and estimated absorption loss at the 1/3-octave band center frequencies (Francois and Garrison 1982: see methods section Sound Attenuation with Range). The source levels for the bands centered at 3.2, 4, 5, and 6.3 kHz are 169.9, 173.2, 171.2, and 166.2 dB re 1 μPa^{2}s at 1 m, respectively.

Fig. 3.34 shows rms pulse length vs. range for the sub-bottom profiler, with rms SPL for comparison. The pulse duration generally increases with range, and the in-beam direct-path pulses at close range are visibly shorter than the out-of-beam measurements.

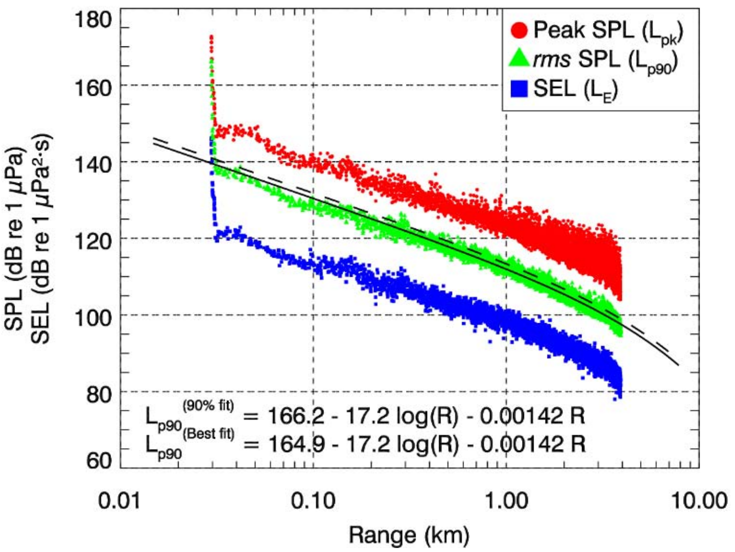


FIGURE 3.29. Kongsberg SBP300 sub-bottom profiler peak SPL, rms SPL, and sound exposure level (SEL) versus slant range at the measurement site. Solid line is best fit of the empirical function to SPL$_{rms90}$ values. Dashed line is the best-fit adjusted to exceed 90% of the SPL$_{rms90}$ values. Acoustic data were band-pass filtered between 1 and 10 kHz before calculating sound levels. Only the shortest range measurements lie in the near-vertical sonar beam.

TABLE 3.14. Kongsberg SBP300 sub-bottom profiler threshold radii at the measurement site as determined from SPL_{rms90} versus distance data in Fig. 3.29. These represent out-of beam levels.

SPL_{rms90} Threshold (dB re 1 µPa)	Best-Fit Line Radius (m)	90th Percentile Radius (m)
160	-	30*
150	-	30*
140	28	34
130	110	130
120	380	450
110	1200	1400

*Actual maximum slant range that the threshold was exceeded. Not from fit function.

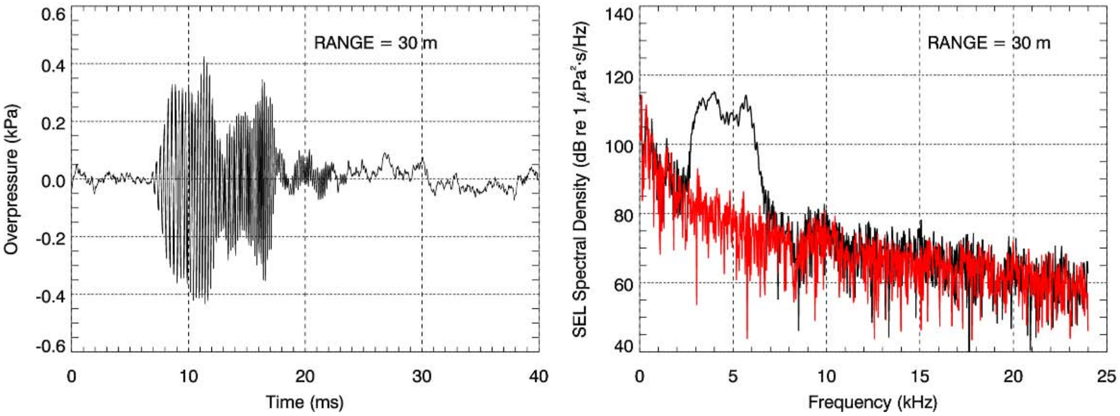


FIGURE 3.30. Kongsberg SBP300 sub-bottom profiler waveform (left) and SEL spectral density plot (right) over 40 ms of one 2- to 7-kHz pulse at 30 m (33 yd) slant range with background noise from the previous 40 ms in red for comparison.

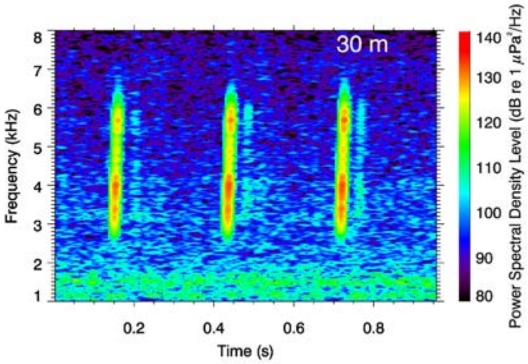


FIGURE 3.31. Kongsberg SBP300 sub-bottom profiler spectrogram of three pulses measured on OBH A at 30 m (33 yd) slant range. 48 ksps, 2048-pt FFT, 87.5% overlap, Hanning window.

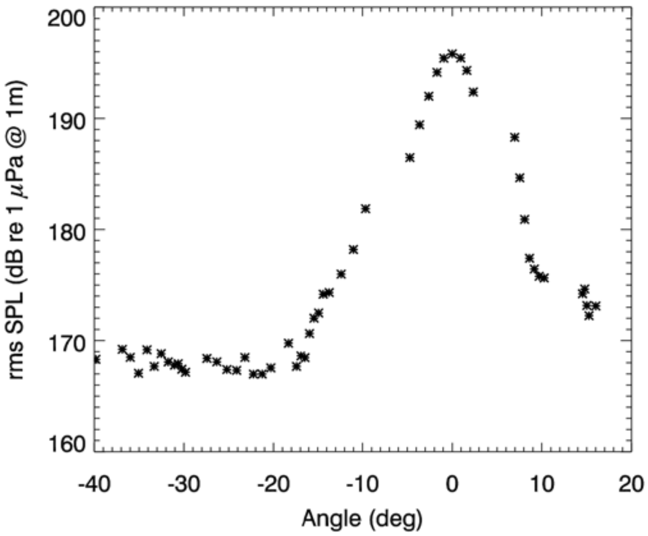


FIGURE 3.32. Kongsberg SBP300 sub-bottom profiler rms SPL source level versus angle off vertical (straight down) measured as the *Duke* sailed directly over the recorder.

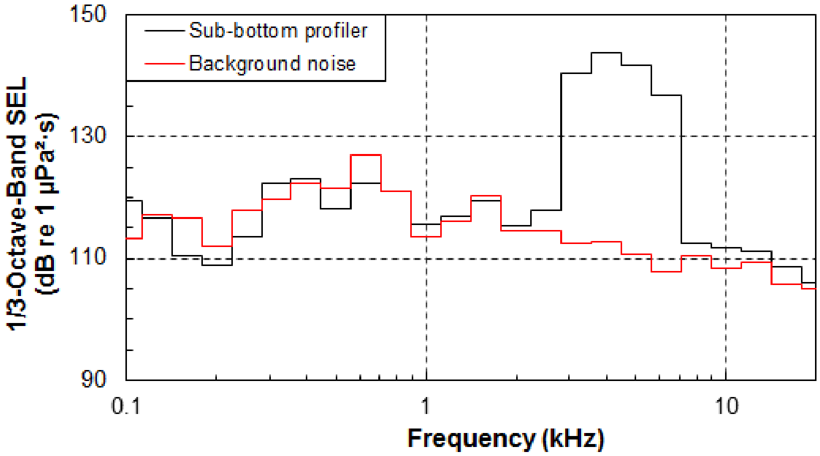


FIGURE 3.33. Kongsberg SBP300 sub-bottom profiler 1/3-octave band SEL over a 30-ms time window. Data were averaged from three in-beam pulses, measured at 31 – 32 m (34 – 35 yd) slant range. The corresponding average band levels of background noise from the three preceding 30-ms windows are shown in red.

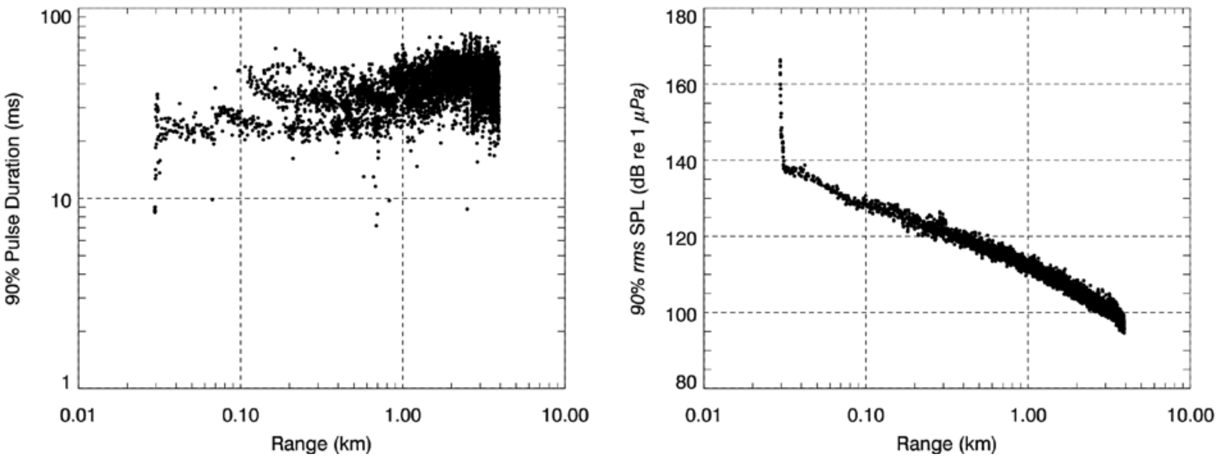


FIGURE 3.34. Kongsberg SBP300 sub-bottom profiler 90% pulse duration and rms SPL as a function of range. Sub-bottom profiler pulses occurred every 0.28 seconds.

GeoAcoustics 159D Side-Scan Sonar Measurements

Peak SPL, 90% rms SPL and SEL for each side-scan sonar pulse were computed from acoustic data from Lines 1-5 of the high-frequency measurement, filtered between 100 and 125 kHz. Side-scan sonar pulses occurred once every 0.2 seconds. Fig. 3.35 shows the in-beam sound level versus range data from the measurement site. Using in-beam levels instead of out-of beam levels provides conservative estimates of threshold distances. Side-scan (and multibeam) sonars have beams that are directed horizontally away from their transducers. The 3 dB beamwidths are very narrow (typically less than 2 degrees) but nevertheless sweep out a swath on either side of the tow vessel over the course of a track line. To provide adequate sampling of the main beam, we have considered three pulses measured on Line 1, six from Line 2, and 10 each from Lines 3-5. The highest in-beam pulse level at 21.9 m (24 yd) CPA was 184.7 dB re 1 μPa. This corresponds with an in-beam source level of 211.5 dB re 1 μPa rms.

Table 3.15 shows ranges to the 180 dB to 140 dB re 1 μPa rms SPL thresholds which were computed from the 90th percentile empirical curve fits to the in-beam SPL versus distance data. Fig. 3.36 shows a waveform and SEL spectral density plot of one pulse at 22 m (24 yd) slant range. In the spectrum plot, background noise from a time window immediately preceding the pulse is plotted in red for comparison. The main pulse is clearly visible at 110 kHz, with harmonics visible near 220 and 340 kHz. The strong tones at 130, 170, 220, 260, 300 kHz etc. are omnipresent in the high-frequency recordings and are unrelated to the side-scan sonar. Fig. 3.37 shows a spectrogram of three side-scan sonar pulses around CPA. The slight trail after each 2-ms pulse represents a received reflection.

Fig. 3.38 shows the azimuthal source level beam pattern from track line 1 measurements of the side-scan sonar. The rms SPL of each pulse was back-propagated using 20log*R* (spherical) spreading and estimated absorption loss at the pulse center frequency (Francois and Garrison 1982: see methods section Sound Attenuation with Range), and the angle at which each was received. Levels were highest ±3° from broadside, and special side lobes of the sonar are evident at approximately ±20° and ±56°.

Fig. 3.39 shows 1/3 octave band levels calculated from the average of the three highest-rms amplitude pulses around CPA, over 15 ms, with the average background noise from the 15-ms windows preceding each pulse plotted in red for comparison. The side-scan sonar pulses exceed background levels in the bands centered between 63 and 126 kHz. The 25- and 32-kHz bands are higher than background due to a USBL beacon pulse that occurred at the same time as the side-scan sonar pulses. A harmonic of the side-scan sonar pulse, shown in Fig. 3.36 causes the excess in the 250-kHz band.

Third-octave band source levels were estimated by back-propagation of filtered (60–125 kHz for the main lobe, 220–240 kHz for the multiple) levels assuming 20log*R* (spherical) spreading and estimated absorption loss at the 1/3-octave band center frequencies (Francois and Garrison 1982: see methods section Sound Attenuation with Range). The source levels for the bands centered at 63, 79, 100, 125, and 250 kHz are 132.0, 140.1, 166.6, 174.2 and 146.7 dB re 1 µPa^{2}s at 1 m (1.1 yd), respectively.

Fig. 3.40 shows rms pulse length vs. range for the side-scan sonar, with rms SPL for comparison. The pulse duration generally increases with range, with slight variations caused by background noise and multipath arrivals. This pattern is more prominently seen in the 40 in^3 array and 10 in^3 mini-airgun results (Fig. 3.15 and Fig. 3.22) and is explained in the discussion section.

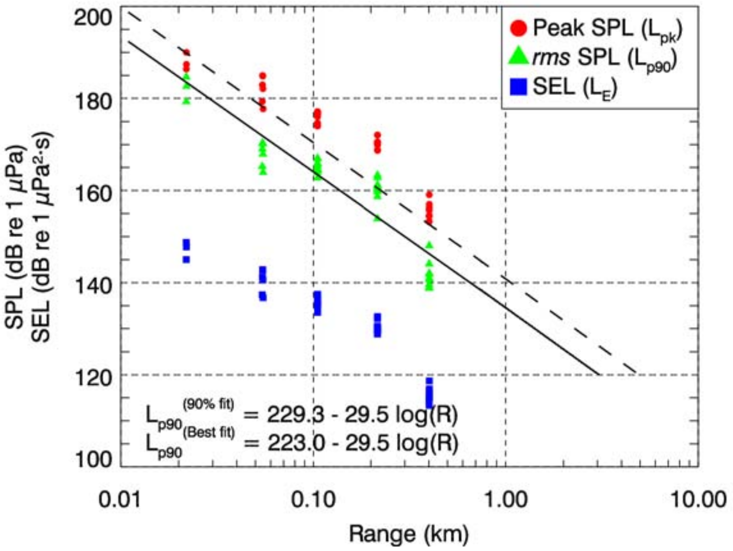


FIGURE 3.35. GeoAcoustics 159D side-scan sonar peak SPL, rms SPL, and sound exposure level (SEL) versus slant range for in-beam pulses at the measurement site. Solid line is best fit of the empirical function to $\text{SPL}_{\text{rms90}}$ values. Dashed line is the best-fit adjusted to exceed 90% of the $\text{SPL}_{\text{rms90}}$ values. Acoustic data were band-pass filtered between 100 and 125 kHz before calculating sound levels.

TABLE 3.15. GeoAcoustics 159D side-scan sonar threshold radii at the measurement site as determined from $\text{SPL}_{\text{rms90}}$ versus distance data in Fig. 3.35.

$\text{SPL}_{\text{rms90}}$ Threshold (dB re 1 μPa)	Best-Fit Line Radius (m)	90th Percentile Radius (m)
190	13*	22
180	29	47
170	63	100
160	140	230
150	300	490**
140	660**	1100**
130	1400**	2400**
120	3100**	5100**

* Extrapolated to shorter distance than the minimum measured range of 21.9 m.
**Extrapolated beyond maximum measured range of 400 m.

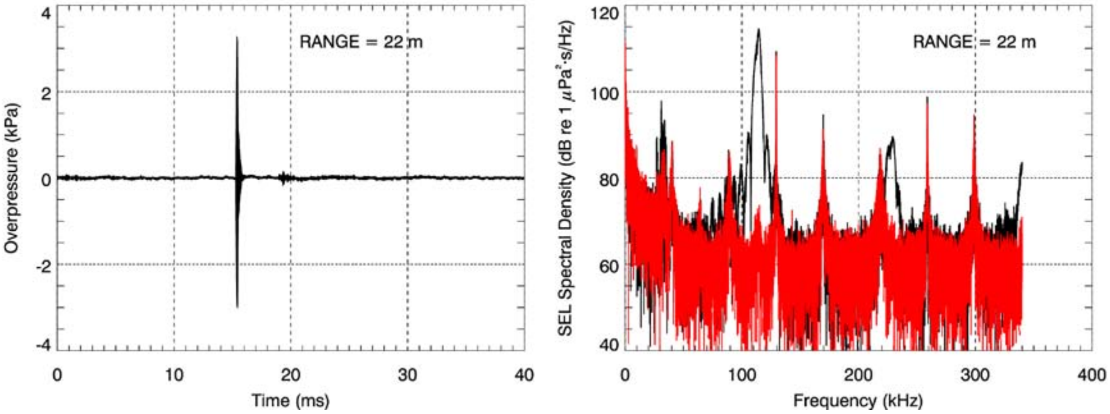


FIGURE 3.36. GeoAcoustics 159D side-scan sonar waveform (left) and SEL spectral density plot (right) over 40 ms of one 110-kHz pulse at 22 m (24 yd) slant range with background noise from the previous 40 ms in red for comparison.

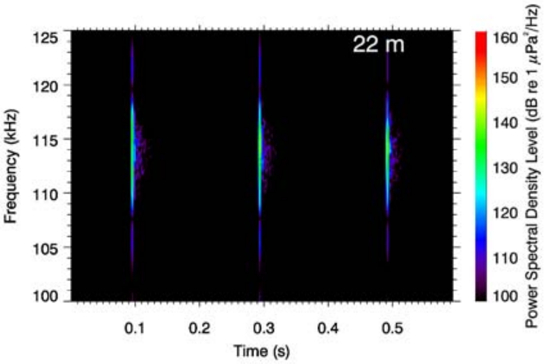


FIGURE 3.37. GeoAcoustics 159D side-scan sonar spectrogram of three pulses measured on OBH A at 22 m (24 yd) slant range. 687.5 ksps, 4096-pt FFT, 87.5% overlap, Hanning window.

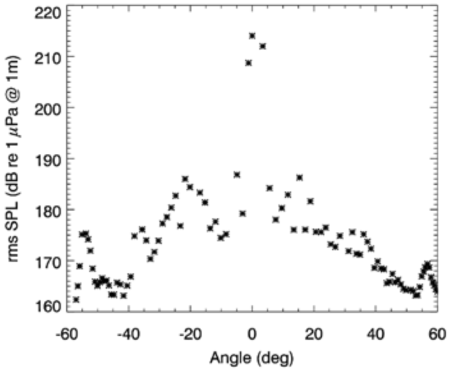


FIGURE 3.38. GeoAcoustics 159D side-scan sonar rms SPL source level versus angle off broadside measured as the *Duke* sailed past the recorders.

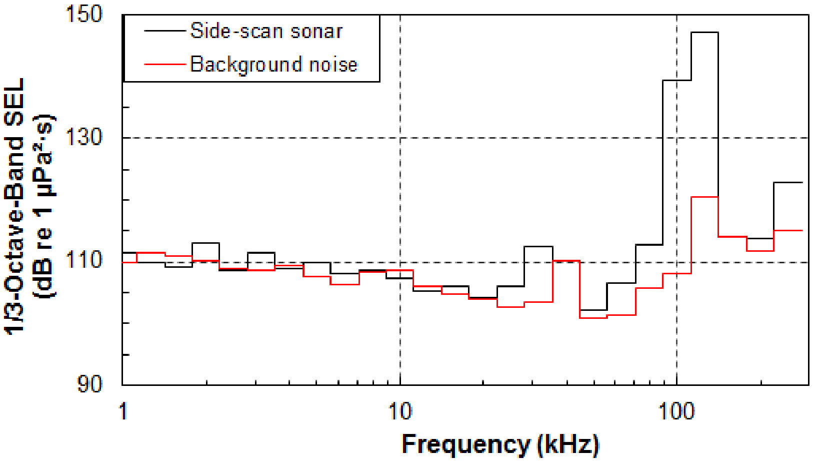


FIGURE 3.39. GeoAcoustics 159D side-scan sonar 1/3-octave band SEL over a 15-ms time window. Data were averaged for three in-beam pulses, each measured at 24 m (26 yd) slant range. The corresponding average band levels of background noise from the three preceding 15-ms windows are shown in red.

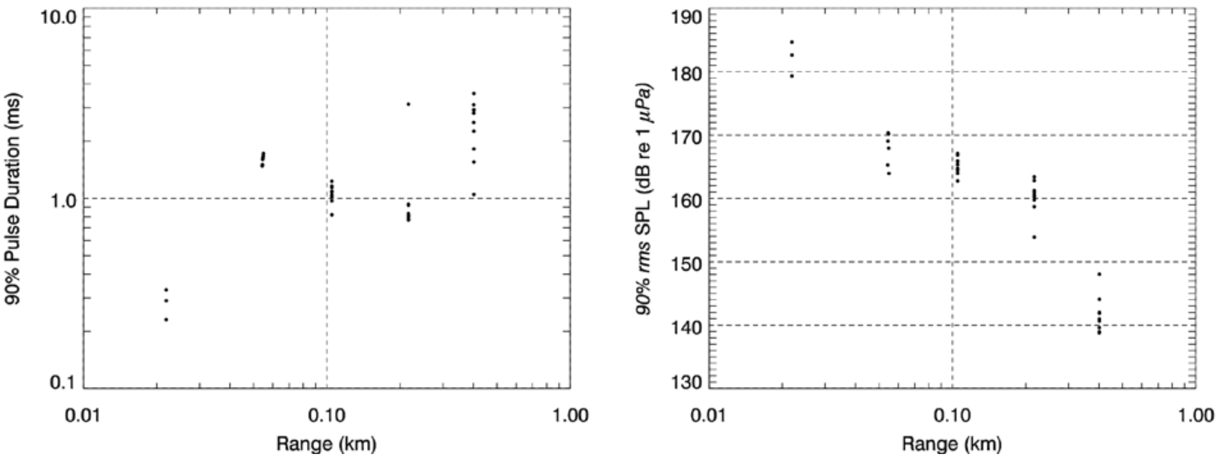


FIGURE 3.40. GeoAcoustics 159D side-scan sonar 90% pulse duration and rms SPL as a function of range. Side-scan sonar pulses occurred every 0.2 seconds.

Kongsberg EM2040 Multibeam Sonar Measurements

Peak SPL, 90% rms SPL and SEL for each multibeam sonar pulse were computed from acoustic data from Lines 1-3 of the high-frequency measurement. Measurements of in-beam levels were performed similarly to the measurements as described for the GeoAcoustics side-scan sonar. Multibeam sonar pulses were not detected for Lines 4 and 5 of the high-frequency measurement, perhaps due to a limited fan angle of the beams produced by this transducer. Pulses occurred once every 0.145 seconds.

Fig. 3.41 presents sound level versus range data for the multibeam sonar. To provide conservative threshold radii, only in-beam measurements from each line are included in the plot. The measurements include two pulses measured on Line 1, four from Line 2, and nine from Line 3. Table 3.16 shows ranges to the 150 dB to 120 dB re 1 μPa rms SPL thresholds. Fig. 3.42 shows a waveform and SEL spectral density plot of one pulse at 30 m (33 yd) slant range. The waveform has been band-pass filtered between 180 and 230 kHz. In the spectrum plot, background noise from a time window immediately preceding the pulse is plotted in red for comparison. Fig. 3.43 shows a spectrogram of two multibeam sonar pulses at CPA. The tones at 130, 170, 220, 260 and 300 kHz are omnipresent in the high-frequency recordings and are unrelated to the multibeam sonar.

The azimuthal beam pattern of the multibeam sonar was calculated using the filtered rms SPL. SPL was back-propagated using 20log*R* (spherical) spreading and absorption loss at the multibeam center frequency to get the source levels of the multibeam (Francois and Garrison 1982: see methods section Sound Attenuation with Range). For each pulse, the azimuthal angle off broadside was calculated using the GPS logs and the AMAR deployment position. Fig. 3.44 shows the resulting source level beam pattern plot. The beam is narrow, with source levels more than 10 dB lower at 2 degrees off broadside. No spatial side lobes were found.

Fig. 3.45 shows 1/3-octave band levels of the highest rms-amplitude pulse at CPA and of the background noise from a 4-ms window preceding the pulse. Band levels from the multibeam exceed background noise levels in the 200- and 250-kHz bands. A USBL beacon pulse concurrent with the multibeam pulse analyzed here caused 1/3-octave band levels in the 25- and 31.5-kHz bands to exceed background noise levels. Noise levels in these bands are not due to the multibeam sonar.

Third-octave band source levels for the multibeam sonar were estimated by back-propagating filtered levels from the highest rms-amplitude pulse, using 20log*R* (spherical) spreading and absorption loss at the 1/3-octave band center frequencies (Francois and Garrison 1982: see methods section Sound Attenuation with Range). The source levels for the 1/3-octave bands centered at 200 and 250 kHz are 144.7 and 138.2 dB re 1 µPa^{2}s at 1 m (1.1 yd), respectively.

Fig. 3.47 illustrates how rms pulse duration varied with range. The pulse duration increased with range because more multipath arrivals reached the recorder.

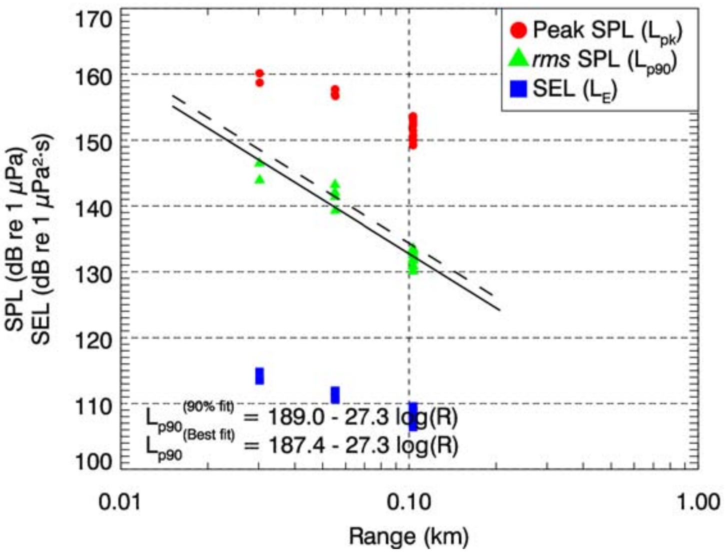


FIGURE 3.41. Kongsberg EM2040 multibeam sonar peak SPL, rms SPL, and sound exposure level (SEL) versus slant range for in-beam pulses at the measurement site. Solid line is best fit of the empirical function to $\mathrm{SPL}_{\mathrm{rms90}}$ values. Dashed line is the best-fit adjusted to exceed 90% of the $\mathrm{SPL}_{\mathrm{rms90}}$ values. Acoustic data were band-pass filtered between 180 and 230 kHz before calculating multibeam sound levels.

TABLE 3.16. Kongsberg EM2040 multibeam sonar threshold radii at the measurement site as determined from $\mathrm{SPL}_{\mathrm{rms90}}$ versus distance data in Fig. 3.41.

$\mathrm{SPL}_{\mathrm{rms90}}$ Threshold (dB re 1 µPa)	Best-Fit Line Radius (m)	90th Percentile Radius (m)
150	23	27
140	54	62
130	130*	140*
120	290*	330*

*Extrapolated beyond maximum measured range of 100 m.

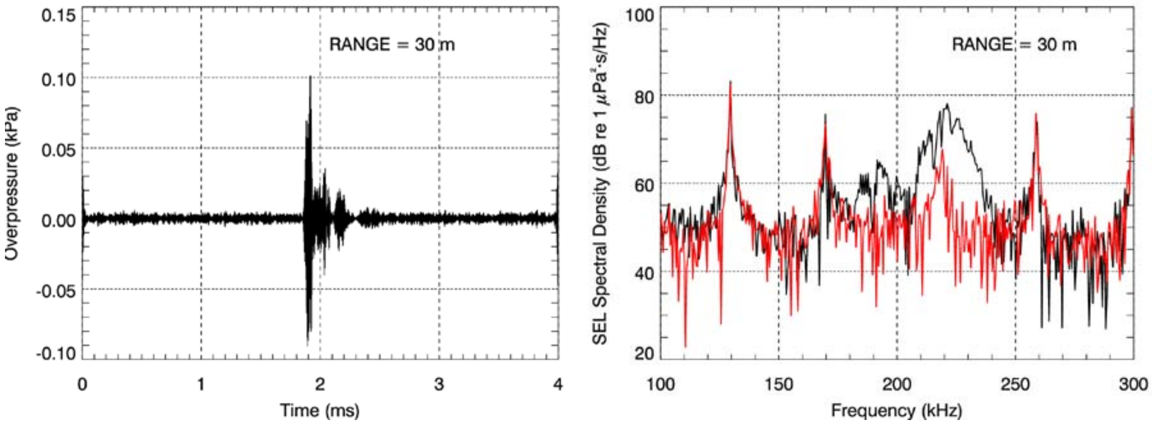


FIGURE 3.42. Kongsberg EM2040 multibeam sonar waveform (left) and SEL spectral density plot (right) over 4 ms of one 220-kHz pulse at 30 m (33 yd) slant range with background noise from the previous 4 ms in red for comparison. The waveform has been band-pass filtered between 180 and 230 kHz.

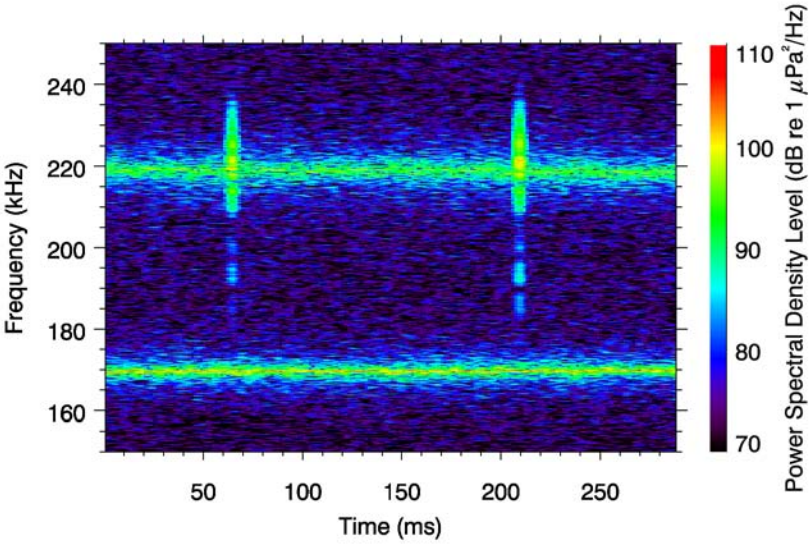


FIGURE 3.43. Kongsberg EM2040 multibeam sonar spectrogram of two pulses measured on the AMAR at 30 m (33 yd) slant range. 687.5 ksps, 8192-pt FFT, 87.5% overlap, Hanning window. Background noise at 170 and 220 kHz is omnipresent in the high-frequency recordings and are unrelated to the multibeam system.

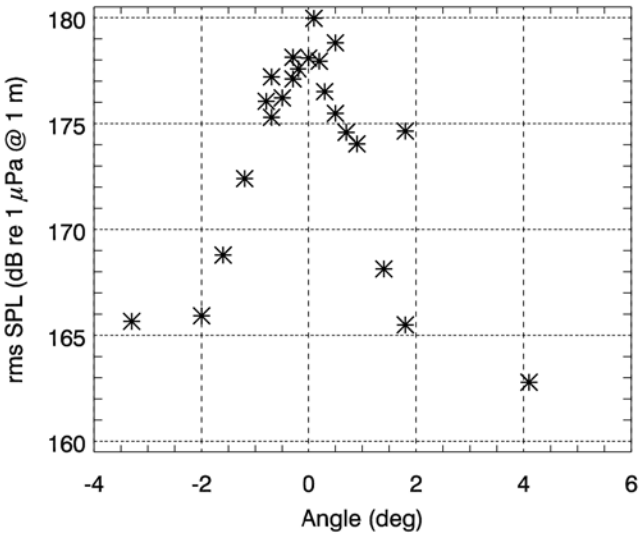


FIGURE 3.44. Kongsberg EM2040 multibeam sonar rms SPL source level versus angle off broadside measured as the *Duke* sailed past the recorders.

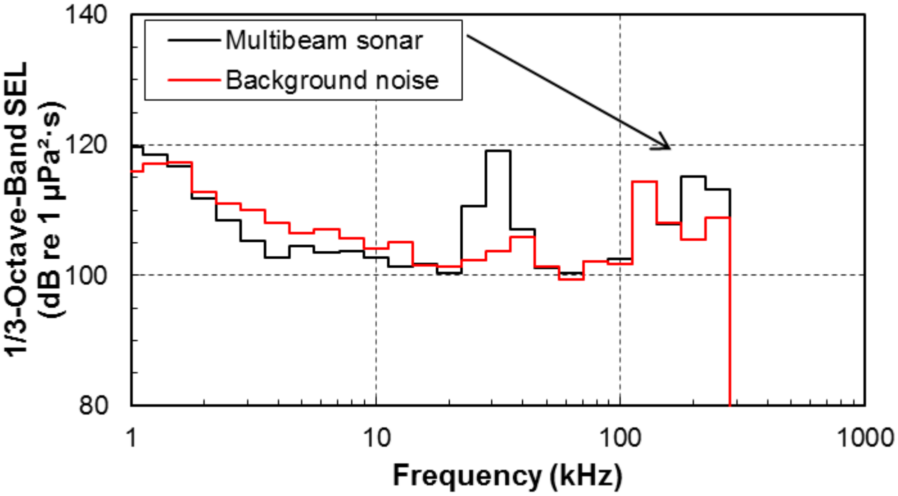


FIGURE 3.45. Kongsberg EM2040 multibeam 1/3-octave band SEL over a 4-ms time window from the highest rms-amplitude pulse measured at the CPA of 30 m (33 yd) slant range. The corresponding band levels of background noise from a preceding 4-ms window are shown in red. Levels in the 25- and 31.5-kHz bands exceeded background levels because of a simultaneous USBL beacon pulse.

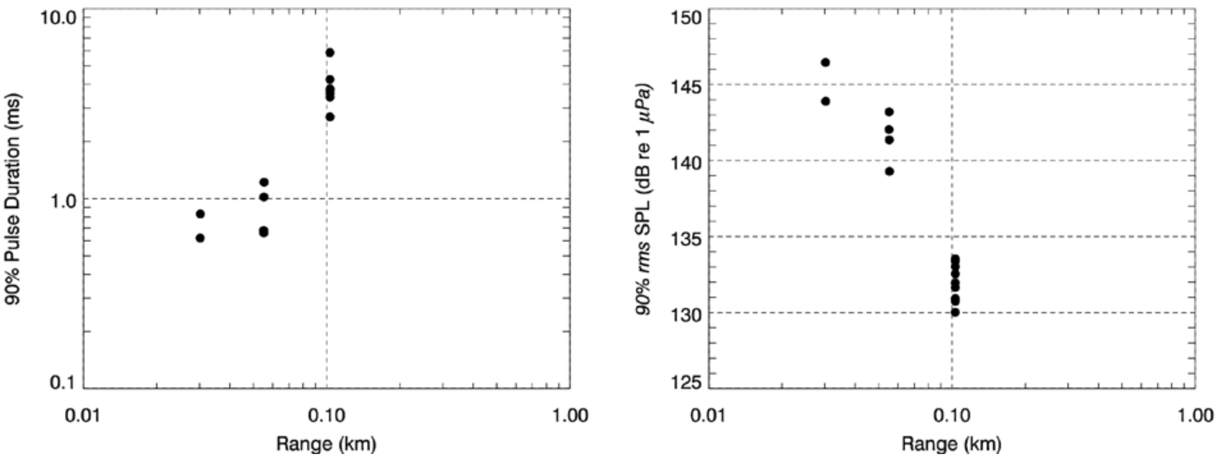


FIGURE 3.46. Kongsberg EM2040 multibeam sonar 90% pulse duration and rms SPL as a function of range. Multibeam pulses occurred every 0.145 seconds.

SonarDyne Ranger Pro USBL Measurements

Peak SPL, 90% rms SPL and SEL for each hull-mounted USBL pulse were computed from acoustic data from Line 1 of the high-frequency measurement. The hull-mounted USBL transducer was pointed 15° towards the stern to communicate with the USBL beacon. USBL pulses occurred once every 2 seconds. Fig. 3.47 presents in-beam and out-of-beam sound level versus range data for the hull-mounted USBL system as it passed the AMAR. In-beam and out-of-beam levels were measured as the hull-mounted USBL system departed and approached the AMAR, respectively. Table 3.17 lists ranges to the 190 dB to 120 dB re 1 μPa rms SPL thresholds.

Fig. 3.48 shows a waveform and SEL spectral density plot of one in-beam pulse at 30 m (33 yd) slant range. The pressure waveform has been band-pass filtered between 26 and 28 kHz for display. In the unfiltered spectrum plot, background noise from a time window immediately preceding the pulse is plotted in red for comparison. Fig. 3.49 shows a spectrogram of two hull-mounted USBL pulses, each followed by two pulses from the USBL beacon. The background noise at 40 kHz is omnipresent in the high-frequency recordings and is unrelated to the USBL system.

Fig. 3.50 shows averaged 1/3-octave band levels from the five highest rms-amplitude pulses near CPA and of the background noise from 36-ms windows preceding each pulse. Band levels from the USBL exceeded background noise levels in the bands centered at 20, 25, and 31.5 kHz. Levels in the 8-kHz band exceeded background levels because of concurrent pulses from the acoustic release attached to the AMAR. Noise in this band is not from the USBL system.

Third-octave band source levels for the hull-mounted USBL system were estimated by back-propagating filtered levels from the five loudest in-beam pulses, based on $20\log R$ (spherical) spreading and absorption loss at the 1/3-octave band center frequencies (Francois and Garrison 1982: see methods section Sound Attenuation with Range). The average source levels for the 1/3-octave bands centered at 20, 25, and 31.5 kHz are 149.9, 173.0, and 151.3 dB re 1 $\mu Pa^2 s$ at 1 m, respectively.

Fig. 3.51 illustrates how in-beam and out-of-beam rms pulse duration varied with range. Pulse duration for in-beam levels was lower than that of out-of-beam levels.

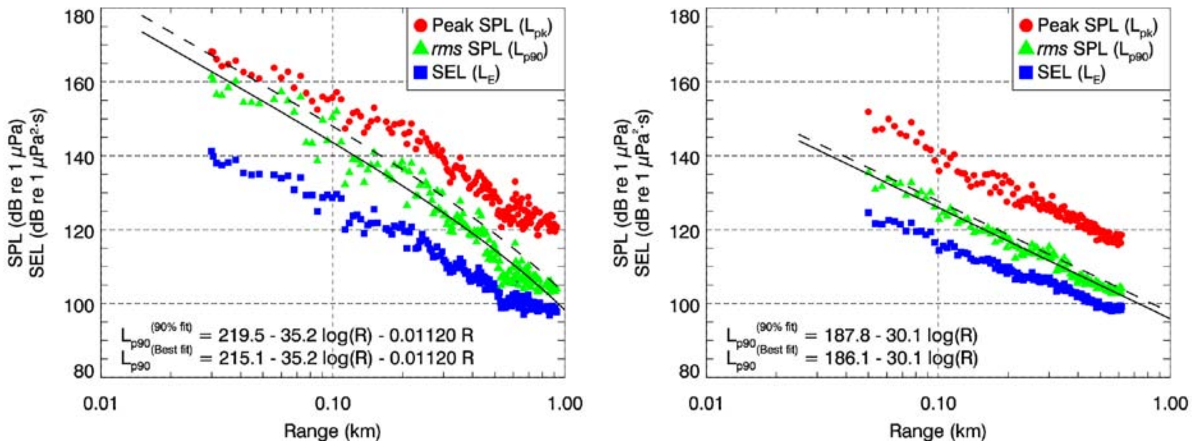


FIGURE 3.47. Hull-mounted SonarDyne Ranger Pro USBL peak SPL, rms SPL, and sound exposure level (SEL) versus slant range for in-beam (left) and out of beam (right) pulses at the *Duke's* measurement site. Solid line is best fit of the empirical function to SPL_{rms90} values. Dashed line is the best-fit adjusted to exceed 90% of the SPL_{rms90} values. Acoustic data were band-pass filtered between 26 and 28 kHz before calculating sound levels.

TABLE 3.17. Hull-mounted SonarDyne Ranger Pro USBL threshold radii at the *Duke's* measurement site as determined from SPL_{rms90} versus distance data in Fig. 3.47.

	In-beam		Out of beam	
SPL_{rms90} Threshold (dB re 1 μPa)	Best-Fit Line Radius (m)	90th Percentile Radius (m)	Best-Fit Line Radius (m)	90th Percentile Radius (m)
190	5*	7*	1**	1**
180	10*	13*	2**	2**
170	19*	25*	3**	4**
160	36	47	7**	8**
150	67	88	16**	18**
140	120	160	34**	39**
130	220	280	73	84
120	380	470	160	180

*Less than minimum measurement range of 30 m.

**Less than minimum measurement range of 50 m.

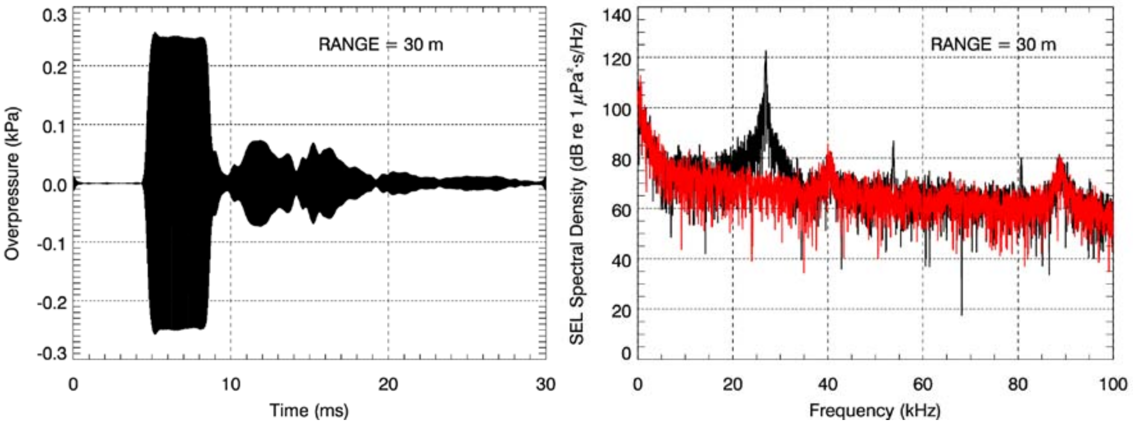


FIGURE 3.48. SonarDyne Ranger Pro USBL waveform (left) and SEL spectral density (right) over 30 ms of one in-beam 27-kHz pulse at 30 m (33 yd) slant range with background noise from the previous 30 ms in red for comparison. The waveform has been band-pass filtered between 26 and 28 kHz. Harmonics at 54 and 71 kHz are above background noise levels.

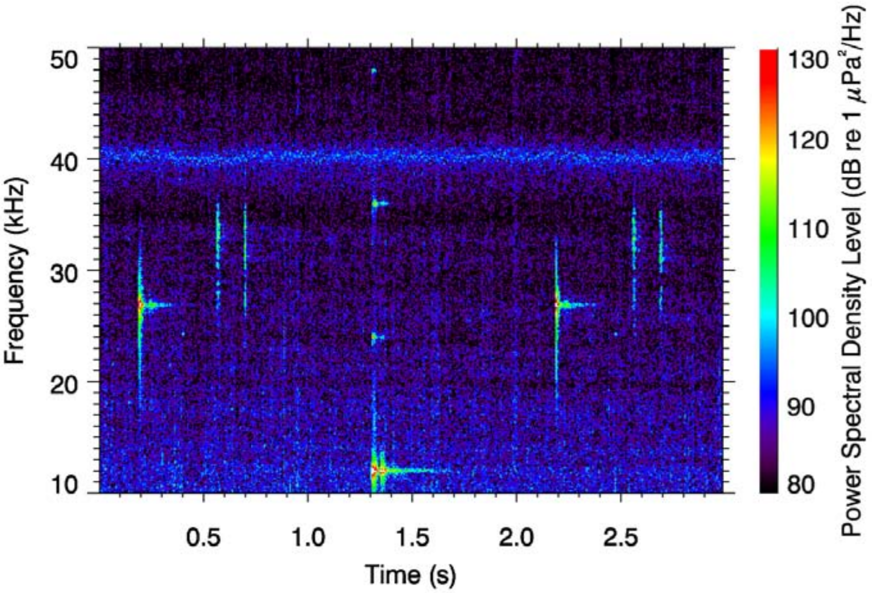


FIGURE 3.49. Spectrogram of two hull-mounted SonarDyne Ranger Pro USBL pulses (centred at 27 kHz), each followed by two pulses from the USBL beacon (between 26 and 36 kHz). 687.5 ksps, 8192-pt FFT, 50% overlap, Hanning window. Data are from the AMAR recording when the hull-mounted USBL system was at 30 m (33 yd) slant range. The pulse centred at 12 kHz with harmonics at 24, 36, and 48 kHz at 1.3 seconds is from the single-beam sonar. Background noise at 40 kHz is omnipresent in the high-frequency recordings and is unrelated to the USBL system.

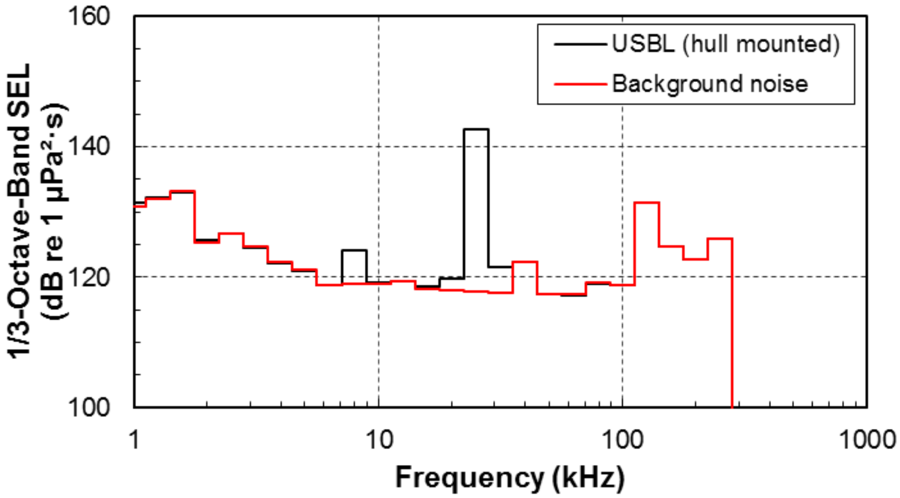


FIGURE 3.50. SonarDyne Ranger Pro USBL average 1/3-octave band SEL over a 36-ms time window. Data were averaged from 5 pulses measured at 32 m (35 yd) slant range. The corresponding band levels of background noise from the preceding 36-ms windows are shown in red. Levels in the 8-kHz band exceeded background levels because of simultaneous pulses from the acoustic release attached to the AMAR.

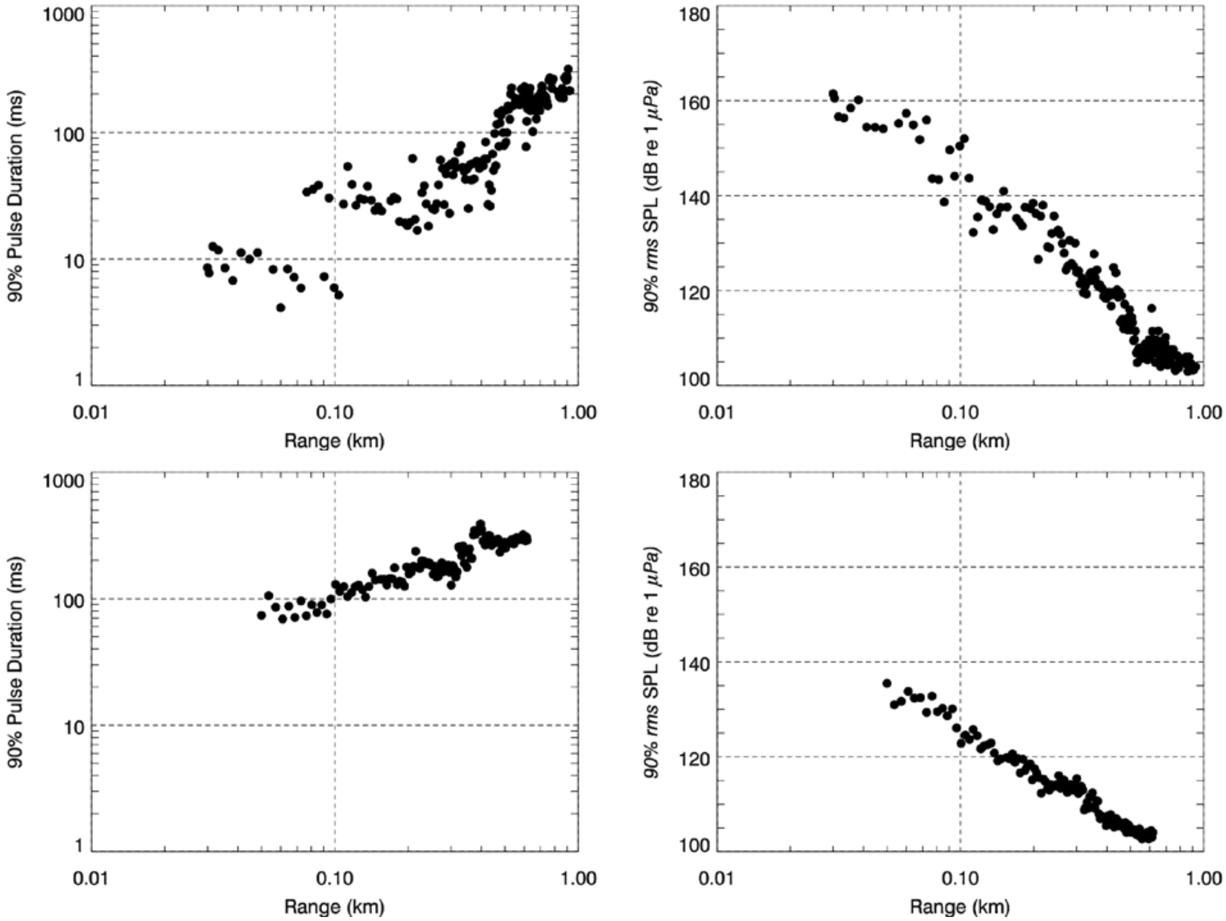


FIGURE 3.51. Hull-mounted SonarDyne Ranger Pro USBL 90% pulse duration and rms SPL as a function of range for in-beam (top) and out-of-beam (bottom) pulses. Hull-mounted USBL pulses occurred once every 2 seconds.

SonarDyne Ranger Pro USBL Beacon Measurements

Peak SPL, 90% rms SPL and SEL for each USBL beacon pulse were computed from acoustic data from Line 1 of the high-frequency measurement. USBL beacon pulses occurred in pairs after each hull-mounted USBL pulse (one pair every 2 seconds), with intra-pair pulse separation of 0.15 ms. Fig. 3.52 presents sound level versus range data for in-beam and out-of-beam pulses from the USBL beacon as it approached and departed the AMAR, respectively. Out-of-beam pulses could not be detected at ranges between 250 to 390 m (273 to 427 yd). Table 3.18 shows ranges to the 160 dB to 120 dB re 1 μPa rms SPL thresholds. The variability in sound level versus range between approximately 100 m and 500 m is explained in the discussion.

Fig. 3.53 illustrates how in-beam and out-of-beam rms pulse duration varied with range. Pulse duration for in-beam measurements were about 10 ms at ranges less than 100 m (109 yd). At further ranges, pulse duration increased but was highly variable. Pulse duration for out-of-beam measurements was highly variable and did not have a significant trend with range.

Fig. 3.54 shows a waveform and SEL spectral density plot of one in-beam pulse at 22 m (24 yd) slant range. The waveform has been band-pass filtered between 26 and 36 kHz. In the spectrum plot, background noise from a time window immediately preceding the pulse is plotted in red for comparison. Fig. 3.49 shows a spectrogram of four pulses from the USBL beacon. The background noise at 40 kHz is omnipresent in the high-frequency recordings and is unrelated to the USBL system.

Fig. 3.55 shows averaged 1/3-octave band levels from the six highest rms-amplitude pulses near CPA and of the background noise from 70-ms windows preceding each pulse. Band levels from the USBL beacon exceeded background noise levels in the bands centered at 25, 31.5, and 40 kHz.

Third-octave band source levels for the USBL beacon were estimated by back-propagating filtered levels from the six loudest in-beam pulses, based on 20log*R* (spherical) spreading and absorption loss at the 1/3-octave band center frequencies (Francois and Garrison 1982: see methods section Sound Attenuation with Range). The average source levels for the 1/3-octave bands centered at 25, 31.5, and 40 kHz are 148.4, 161.4, and 135.8 dB re 1 μPa^{2}s at 1 m (1.1 yd), respectively.

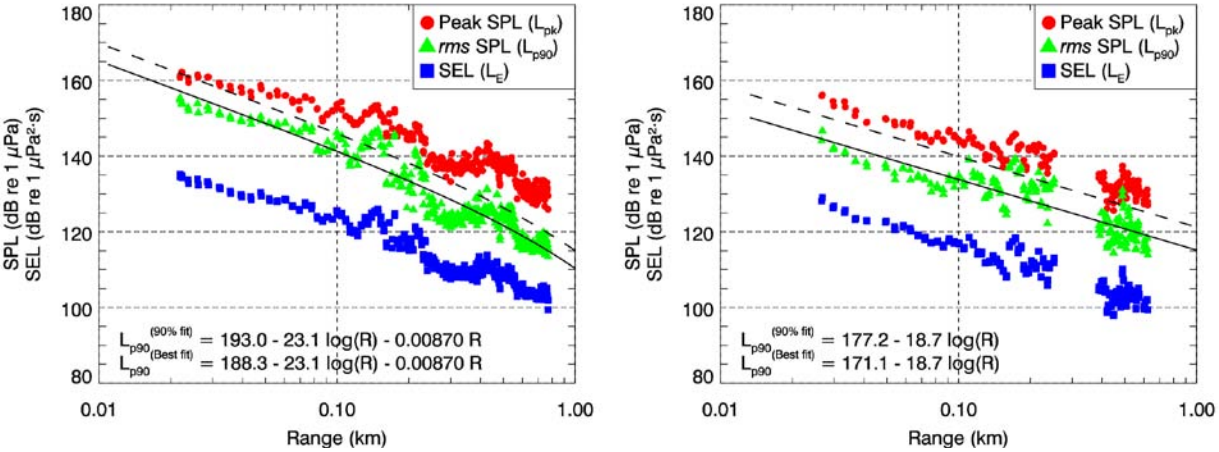


FIGURE 3.52. SonarDyne Ranger Pro USBL beacon peak SPL, rms SPL, and sound exposure level (SEL) versus slant range for in-beam (left) and out of beam (right) pulses at the measurement site. Solid line is best fit of the empirical function to SPL$_{rms90}$ values. Dashed line is the best-fit adjusted to exceed 90% of the SPL$_{rms90}$ values. Acoustic data were band-pass filtered between 26 and 36 kHz before calculating USBL beacon sound levels.

TABLE 3.18. SonarDyne Ranger Pro USBL beacon threshold radii at the *Duke's* measurement site as determined from SPL$_{rms90}$ versus distance data in Fig. 3.52.

	In-beam		Out of beam	
SPL$_{rms90}$ Threshold (dB re 1 μPa)	Best-Fit Line Radius (m)	90th Percentile Radius (m)	Best-Fit Line Radius (m)	90th Percentile Radius (m)
160	17	26	4	8
150	44	69	14	29
140	110	170	47	99
130	270	380	160	340
120	560	750	550	1200*

*This radius is extrapolated beyond the maximum measurement range of 620 m. It is larger than the corresponding in-beam radius primarily because of the large offset required for the 90% fit and likely overestimates the actual distance.

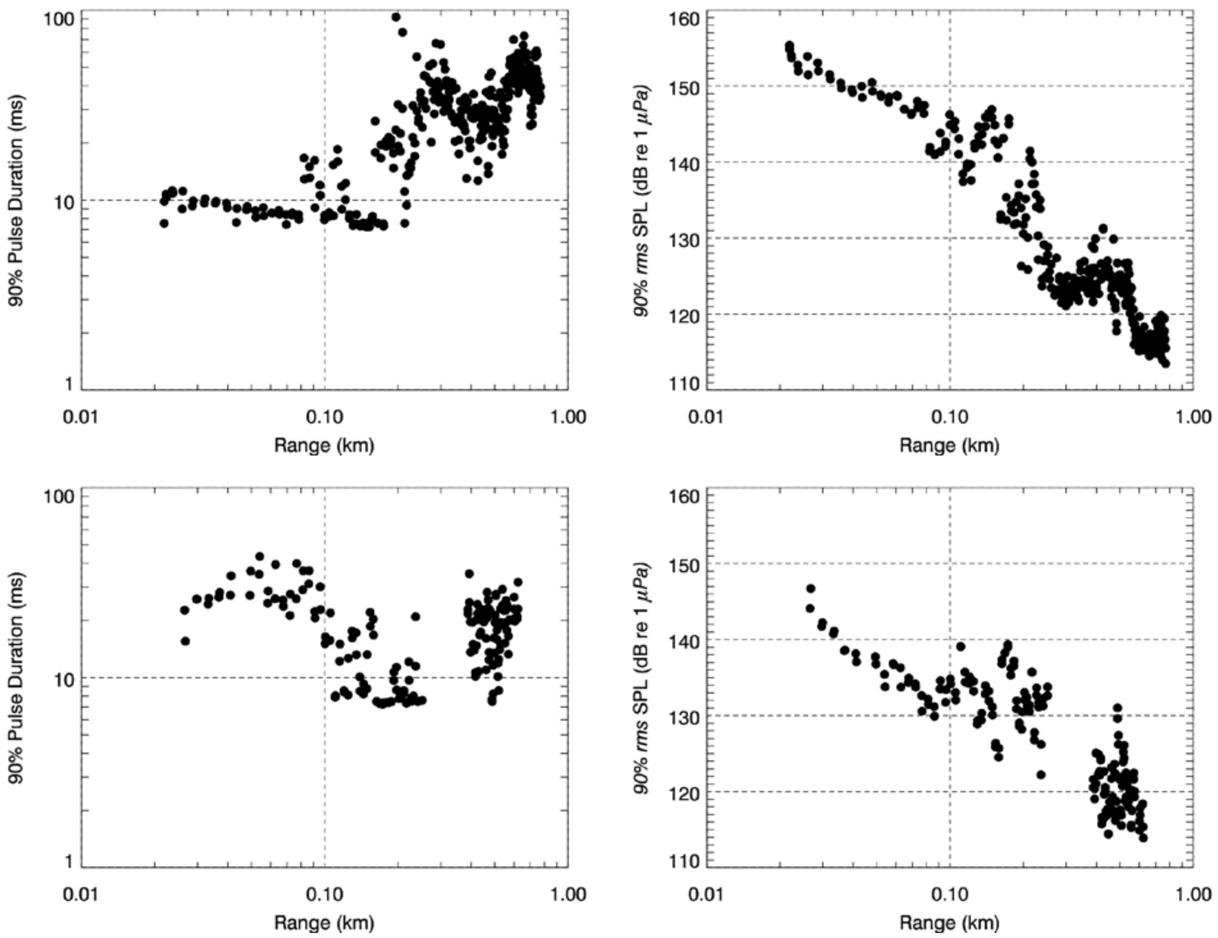


FIGURE 3.53. SonarDyne Ranger Pro USBL beacon 90% pulse duration and rms SPL as a function of range for in-beam (top) and out-of-beam (bottom) pulses. USBL beacon pulses occurred in pairs after each hull-mounted USBL pulse (one pair every 2 seconds), with intra-pair pulse separation of 0.15 ms.

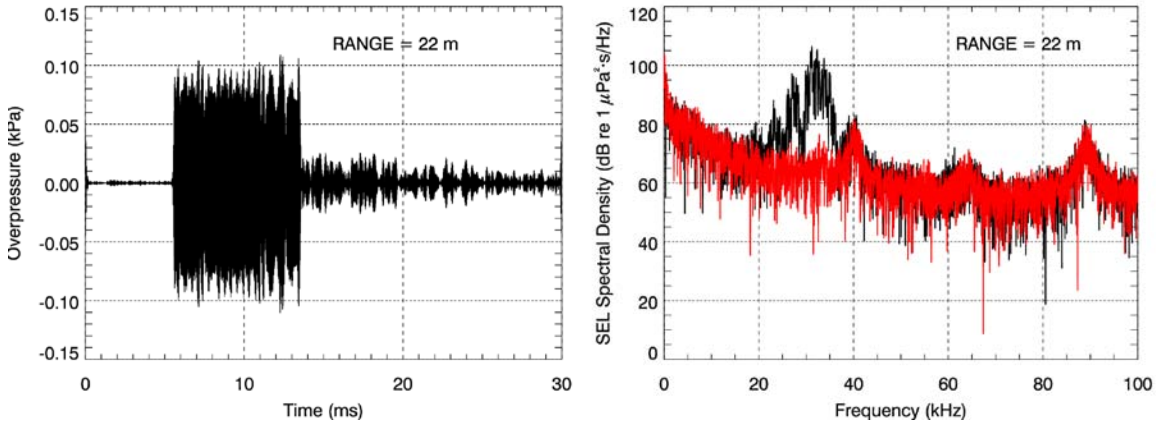


FIGURE 3.54. SonarDyne Ranger Pro USBL beacon waveform (left) and SEL spectral density (right) over 30 ms of one in-beam pulse at 22 m (24 yd) slant range with background noise from the previous 30 ms in red for comparison. The waveform has been band-pass filtered between 26 and 36 kHz.

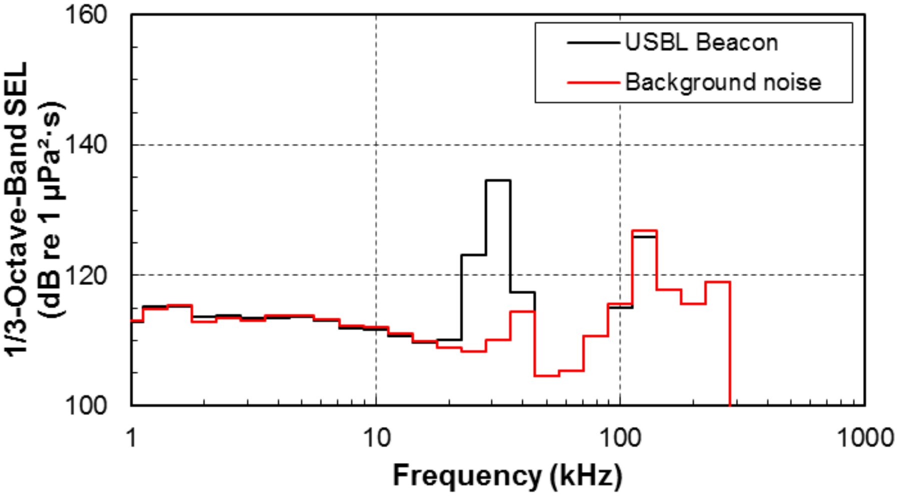


FIGURE 3.55. SonarDyne Ranger Pro USBL beacon 1/3-octave band SEL over a 70-ms time window. Data were averaged from 6 pulses measured at 22 m (24 yd) slant range. The corresponding band levels of background noise from the preceding 70-ms windows are shown in red.

Vessel Noise – M/V Duke

SPLs were computed for vessel self-noise of the *Duke* as it transited away from the OBH recorders. The Kongsberg SBP300 was measured during the vessel approach, so vessel noise was only measured for the departure, starting near the CPA. These levels were computed in consecutive 1 second time windows and represent continous noise levels as opposed to the impulsive levels presented for airgun and sonar sources. Sound levels are plotted as a function of time in Fig. 3.56 to show the evolution of level decrease as the as the vessel departed the OBH. Fig. 3.57 presents the rms levels versus range for the *Duke* vessel noise transiting at 4.5 kts, as well as the best-fit and 90th percentile trend lines and the equations thereof. Data presented in these plots were recorded from the higher sensitivity TC4032 hydrophone. The decrease in sound level approximately 5 minutes after CPA, or equivalently between 600 and 700 m (656 and 766 yd) range, is likely due to the shutdown of a compressor or auxiliary engine on board the *Duke*. The ranges to the sound level thresholds of 160 to 120 dB re µPa (rms) for the *Duke* travelling at 4.5 kts are listed in Table 3.19.

Spectrogram and power spectral density plots for CPA (30 m slant range) are shown in Fig. 3.58 and Fig. 3.59, respectively. Data presented in these plots were recorded using the higher sensitivity hydrophone. The spectrogram clearly shows the expected Lloyd Mirror interference pattern as the *Duke* passed the OBH. A sub-bottom profiler pulse is visible 80 seconds into the spectrogram at frequencies between 3 and 7 kHz.

Fig. 3.60 shows a contour plot of 1/3-octave band levels, versus range and frequency for the *Duke* transiting at 4.5 kts. The contour plot shows the spectral distribution of sound energy versus range, and also shows which frequencies dominated sound propagation at the test site. Sound levels at frequencies below 200 Hz were highest near the vessel and showed the strongest propagation with range.

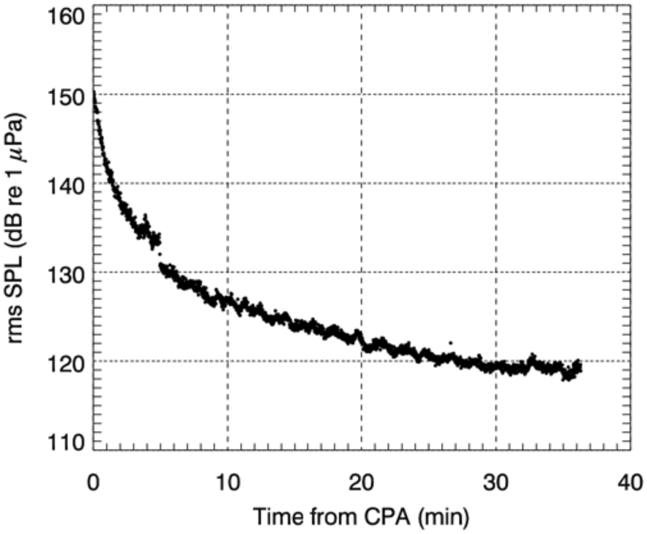


FIGURE 3.56. *Duke* broadband rms SPL as a function of time as the vessel departed the OBH recorder at 4.5 kts. CPA was 30 m (33 yd) slant range. Approach not shown due to operation of the sub-bottom profiler.

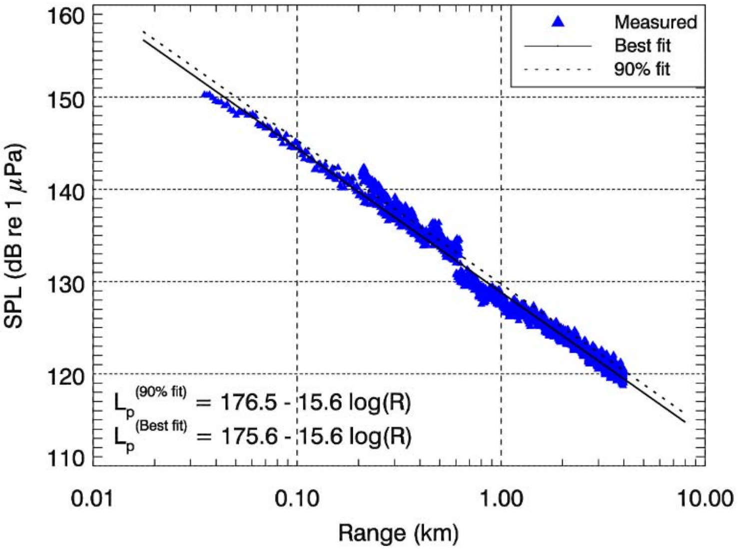


FIGURE 3.57. *Duke* rms SPL versus slant range in the aft direction while it departed the recorders at 4.5 kts. Solid line is best fit of the empirical function to SPL values. Dashed line is the best-fit adjusted to exceed 90% of the SPL values. Data values whose ranges were greater than 4 km were removed from the plot due to recorded values reaching upper range of ambient levels.

TABLE 3.19. *Duke* threshold radii for transiting at 4.5 kts at the measurement site as determined from SPL versus distance data in Fig. 3.57.

SPL_{rms} Threshold (dB re 1 µPa)	Best-Fit Line Radius (m)	90th Percentile Radius (m)
160	10*	11*
150	44	50
140	190	220
130	840	960
120	3400	4200**

*Extrapolated beyond minimum measured range of 35 m.

**Extrapolated beyond maximum measured range of 4 km.

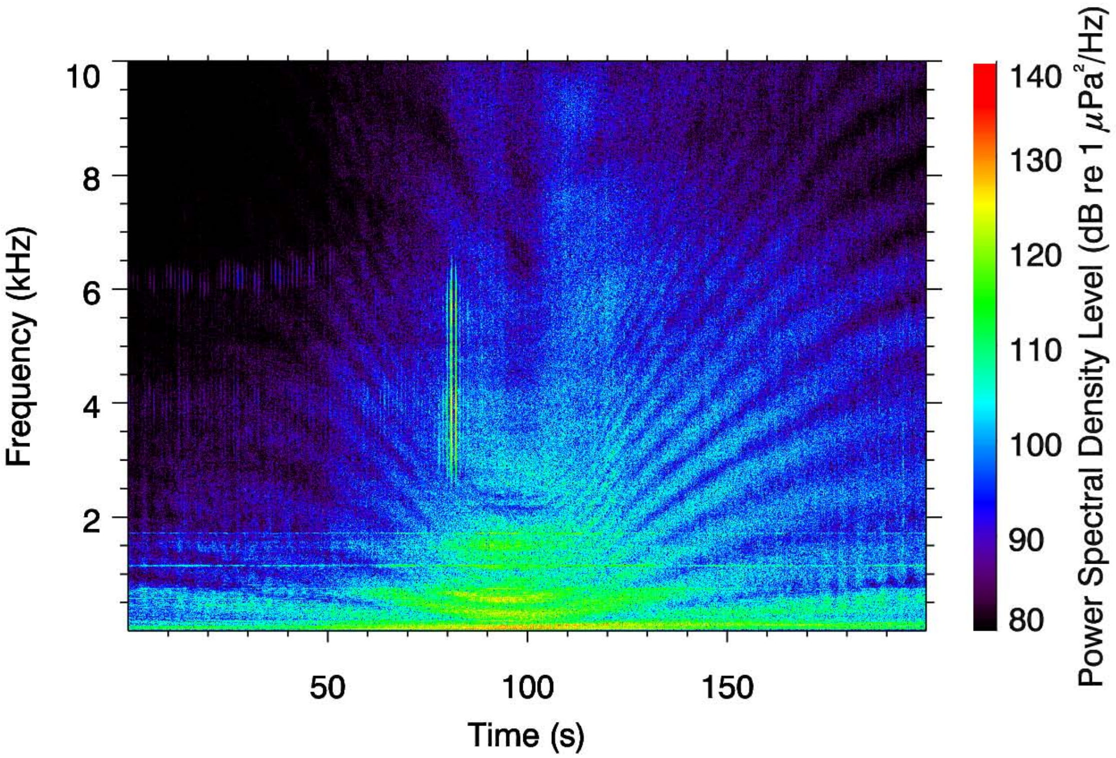


FIGURE 3.58. *Duke* vessel noise spectrogram at CPA (30 m slant range). The *Duke* was travelling at 4.5 kts. 48 ksps, 8192-pt FFT, 87.5% overlap, Hanning window. The 2.5-7 kHz pulse at 80 s is the in-beam sampling of the sub-bottom profiler.

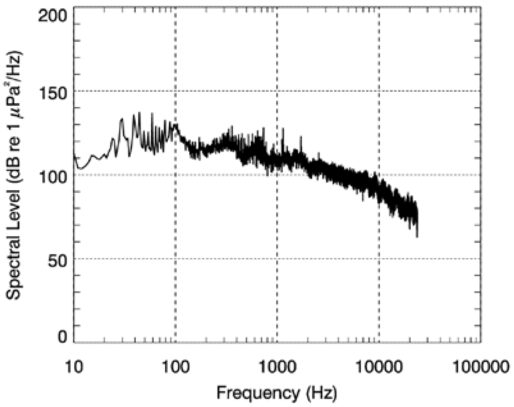


FIGURE 3.59. *Duke's* average unfiltered power spectral density (PSD) from five 1-s windows around the 30 m CPA for transiting at 4.5 kts.

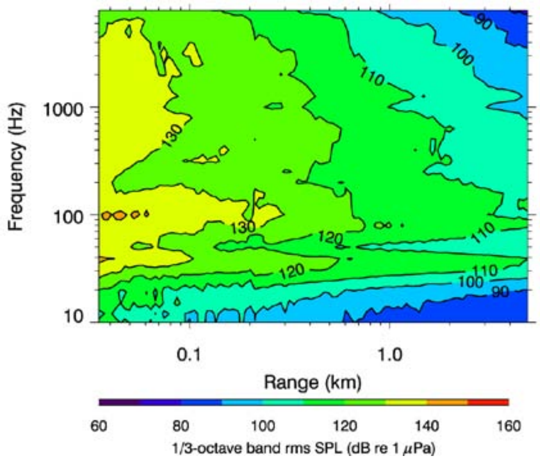


FIGURE 3.60: *Duke* vessel noise third-octave band levels as a function of range and frequency for transiting at 4.5 kts.

Geotechnical Coring Operation (M/V Synergy)

CTD Data

Temperature and sound velocity profiles of the water column at the *Synergy* measurement location were sampled before the test. The profiles were taken at 07:15 on 8 September 2011 (UTC) at 71°46.345'N 164°15.689'W. The water temperature and sound velocity profile obtained showed a well-mixed 16 to 18 m (17.5 to 20 yd) thick layer of warmer surface water (6 °C, 43°F) above a deeper layer of cold water (–1 °C, 30 °F). This resulted in a two-layer sound velocity profile, with a transition from a higher velocity surface layer (1468 m/s, 1605 yd/s) to a lower velocity bottom layer (1442 m/s, 1577 yd/s) between 16 and 24 m (17.5 and 26 yd) depth. The sound velocity profile measured before the test is shown in Fig. 3.61. This profile, having higher sound velocity near the sea-surface, is downward-refracting.

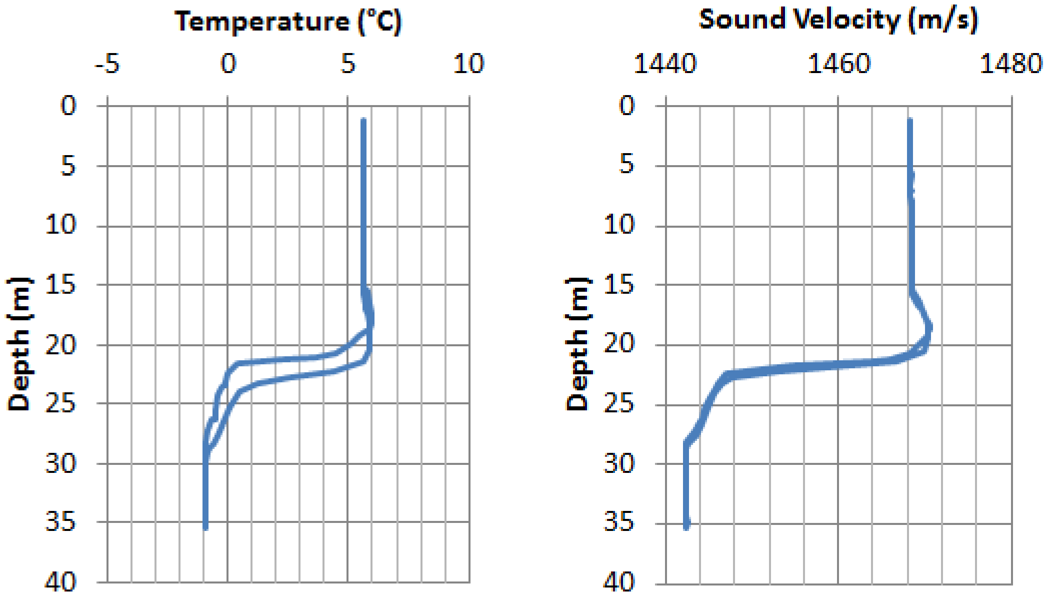


FIGURE 3.61. Measured ocean temperature profile and derived sound velocity profile from 07:15 on 8 September 2011 (UTC) at 71°46.345'N 164°15.689'W.

Kongsberg EA600 Single-Beam Sonar

Peak SPL, 90% rms SPL and SEL for each 18-kHz sonar pulse were computed from acoustic data recorded by OBH A on the more sensitive TC4032 hydrophone, and were band-pass filtered between 16 and 20 kHz. Pulses at 200 kHz were recorded by the AMAR and filtered between 195-205 kHz or 198-202 kHz for in- and out-of-beam measurements, respectively. Single-beam sonar pulses at both frequencies occurred once every 3.33 seconds. Fig. 3.62 and Fig. 3.63 show sound level versus slant range plots for the single-beam sonar operating at each frequency. The fit function for the 18 kHz sonar represents mainly out-of-beam measurements, with a few in-beam measurements apparent at higher levels. The in-beam source level for the single-beam sonar, computed by spherical scaling of the measurement of 163.5 dB re 1 µPa rms made at 37.5 m, is 195.0 dB re 1 µPa rms. The 200 kHz measurement, with few detectable pulses, was split into in-beam and out-of-beam plots with separate fit functions and radii. Spherical scaling of the measurement of 124.9 dB re 1 µPa rms made at 69.8 m (76.3 yd), is 161.8 dB re 1 µPa rms. For both frequencies, the in-beam CPA pulse was loud enough to clip the measurements and was therefore removed. As a result, these back-propagated SLs represent the second-loudest pulses. Table 3.20 and Table 3.21 show ranges to the 190 dB down to 120 dB re 1 µPa rms SPL thresholds which were computed from the 90th percentile empirical curve fits to the SPL versus range data.

Fig. 3.64 shows waveform and SEL spectral density plots of one pulse over 100-ms at each operating frequency at 46 m (50 yd, 18 kHz) and 37 m (40 yd, 200 kHz) slant range. In the spectrum plot, background noise from the 100 ms immediately preceding the pulse is plotted in red for comparison. The main 18-kHz pulse is visible from 12 to 24 kHz, and the main 200-kHz pulse can be seen from 190 to 205 kHz. A tone at 210 kHz in the AMAR recording obscures part of the pulse. Fig. 3.65 shows spectrograms of both single-beam sonar pulses at CPA. Reflections of each initial direct pulse are visible in both plots.

Fig. 3.66 shows the vertical source level beam pattern from measurements of the single-beam sonar as it passed OBH A (18 kHz) and the AMAR (200 kHz). The rms SPL of each pulse was back-propagated using

20log*R* (spherical) spreading and estimated absorption loss at the 1/3-octave band center frequencies (Francois and Garrison 1982: see methods section Sound Attenuation with Range), and the angle at which each was received. Since the source only emitted a pulse every three seconds, the beam pattern is not well resolved near 0°. However, it is still clear that there is primarily a vertical beam since source levels were highest near vertical. The primary beams were limited to ±20° away from vertical, with higher levels on the approach than the departure. For both frequency modes, the vertical 0° CPA pulse has been removed as it caused clipping on the recorder, and therefore an accurate measurement was not obtained. The source level at +35° in the 18 kHz plot is about 6 dB larger than all other levels because the corresponding 90% rms pulse duration was only several ms.

Fig. 3.67 shows 1/3 octave band levels for 18-kHz single-beam sonar operation, calculated from the average of four 25-ms pulses with the highest rms amplitude around the 37-m CPA. The average background noise from the 25-ms windows preceding each pulse are plotted in red for comparison. The single-beam sonar pulses exceed background levels in the bands centered between 12.6 and 20 kHz, with the greatest excess contained in the 20-kHz band. Fig. 3.68 shows corresponding levels for 200-kHz pulses, using three 30-ms pulse windows near the 37m (40 yd) CPA. These pulses exceed background noise only in the 200 kHz band; the large difference in lower frequency bands is due to simultaneous 18 kHz pulses and their harmonics.

Third-octave band source levels were estimated by back-propagating filtered levels assuming 20log*R* (spherical) spreading and estimated absorption loss at the 1/3-octave band center frequencies (Francois and Garrison 1982: see methods section Sound Attenuation with Range). For the 18 kHz pulses, the source levels in the bands centered at 12.5, 15.8, and 20 kHz are estimated to be 101.4, 163.9, and 171.9 dB re 1 μPa^2s at 1 m (1.1 yd), respectively. For 200-kHz pulses, the source level estimated in the 200-kHz band is 158.0 dB re 1 μPa^2s at 1 m (1.1 yd).

Fig. 3.69 shows rms pulse length vs. range for both operating frequencies of the single-beam sonar, with rms SPL for comparison. The pulse duration generally increases with range, and the short-duration, in-beam pulses are readily apparent.

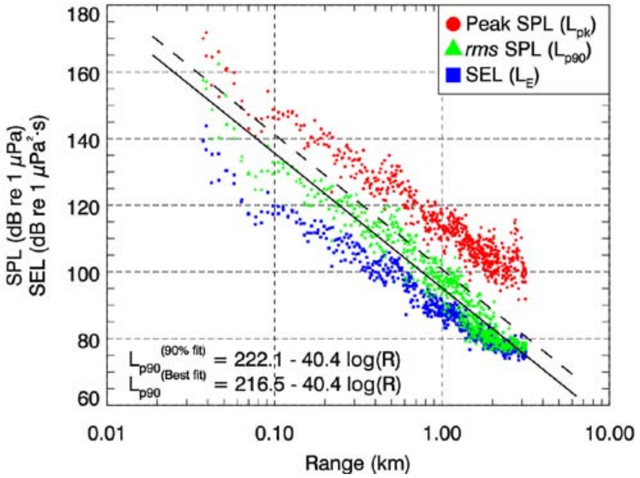


FIGURE 3.62. Kongsberg EA600 single-beam sonar peak SPL, rms SPL, and per-pulse sound exposure level (SEL) versus slant range for pulses at 18 kHz. Solid line is best fit of the empirical function to SPL$_{rms90}$ values. Dashed line is the best-fit adjusted to exceed 90% of the SPL$_{rms90}$ values. Acoustic data were band-pass filtered between 16 and 20 kHz before calculating sound levels.

TABLE 3.20. Kongsberg EA600 single-beam sonar (18 kHz) threshold radii at the measurement location as determined from SPL$_{rms90}$ versus distance data in Fig. 3.62.

SPL$_{rms90}$ Threshold (dB re 1 μPa)	Best-Fit Line Radius (m)	90th Percentile Radius (m)
190	4*	6*
180	7*	11*
170	13*	19*
160	23*	34*
150	41	60
140	74	110
130	130	190
120	240	340

*Extrapolated from a minimum distance of 37 m.

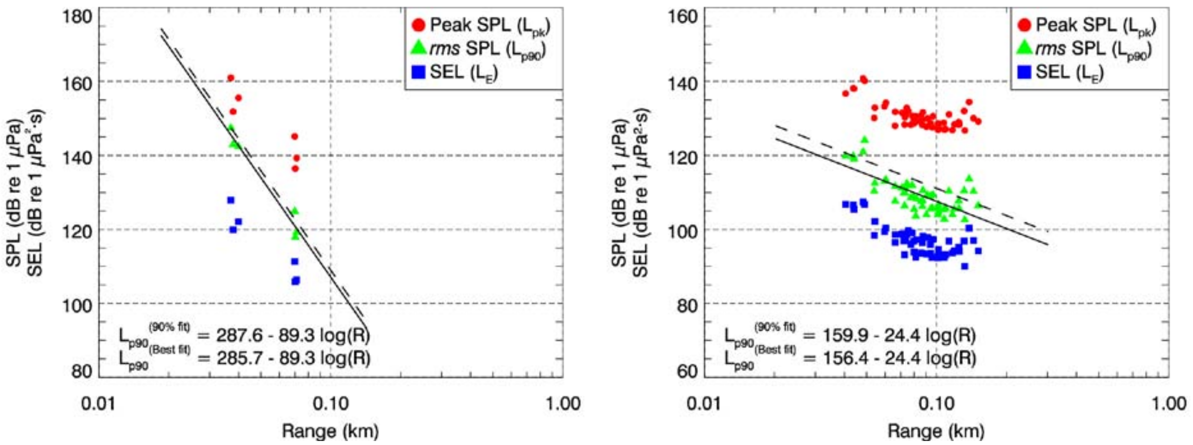


FIGURE 3.63. Kongsberg EA600 single-beam sonar peak SPL, rms SPL, and per-pulse sound exposure level (SEL) versus slant range for pulses at 200 kHz, measured in-beam (left) and out-of-beam (right). Solid line is best fit of the empirical function to $\text{SPL}_{\text{rms90}}$ values. Dashed line is the best-fit adjusted to exceed 90% of the $\text{SPL}_{\text{rms90}}$ values. Acoustic data were band-pass filtered between 195 and 205 kHz (in-beam) or between 198 and 202 kHz (out-of-beam) before calculating sound levels.

TABLE 3.21. Kongsberg EA600 single-beam sonar (200 kHz) threshold radii at the measurement location as determined from $\text{SPL}_{\text{rms90}}$ versus distance data in Fig. 3.63.

$\text{SPL}_{\text{rms90}}$ Threshold (dB re 1 μPa)	In-beam		Out-of-beam	
	Best-Fit Line Radius (m)	90th Percentile Radius (m)	Best-Fit Line Radius (m)	90th Percentile Radius (m)
190	12*	12*	-	-
180	15*	16*	-	-
170	20*	21*	-	-
160	26*	27*	1*	1*
150	33*	35*	2*	3*
140	43	45	5*	7*
130	55	58	12*	17*
120	72	75	31*	43

*Extrapolated from a minimum distance of 37 m.

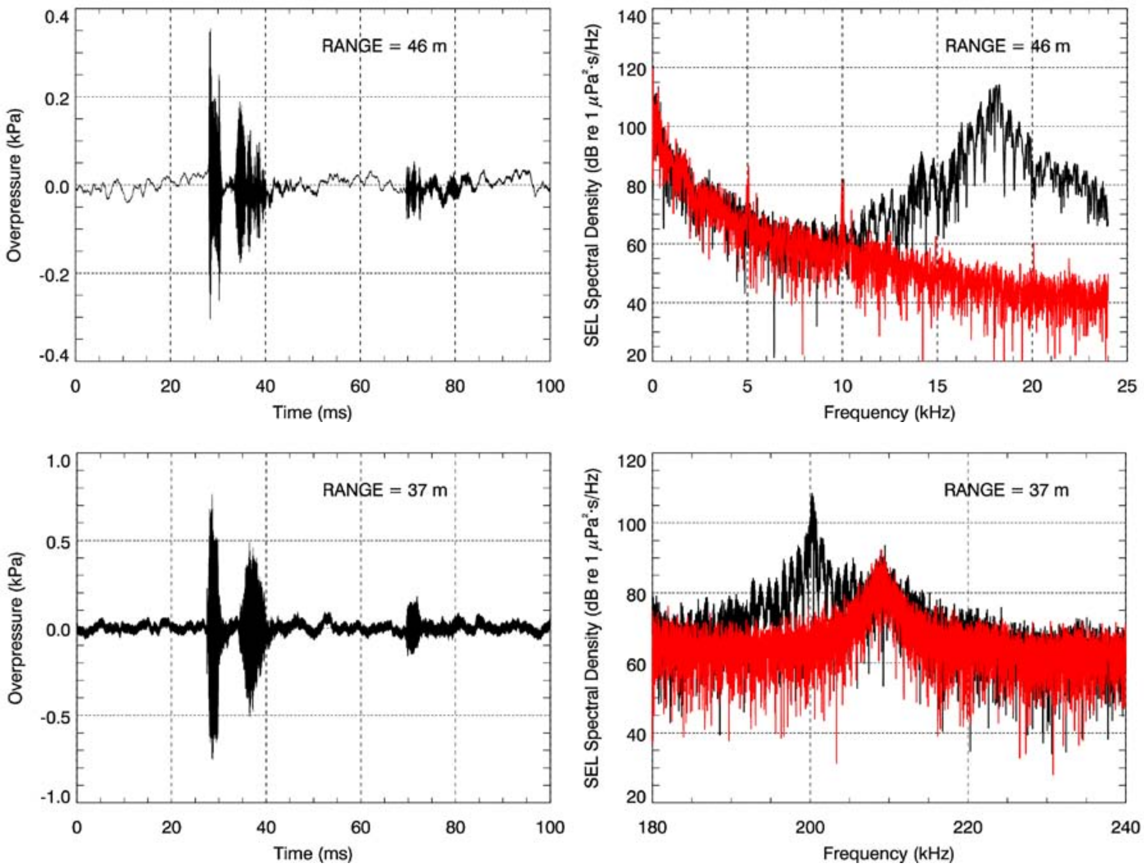


FIGURE 3.64. Kongsberg EA600 single-beam sonar waveform (left) and SEL spectral density (right) over 100-ms of one 18-kHz (top) and 200-kHz (bottom) pulse, at the labeled slant ranges. Background noise from the preceding 100-ms is shown in red for comparison.

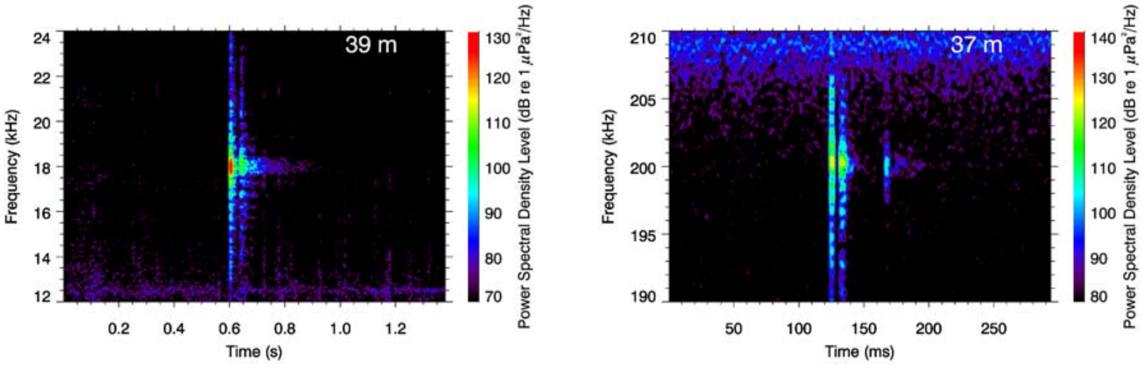


FIGURE 3.65. Kongsberg EA600 single-beam sonar pulse spectrograms at 18 kHz (left), and 200 kHz (right), measured at the labeled slant ranges. 48 ksps, 1024-pt (left) and 687.5 ksps, 4096-pt (right) FFT, 87.5% overlap, Hanning window.

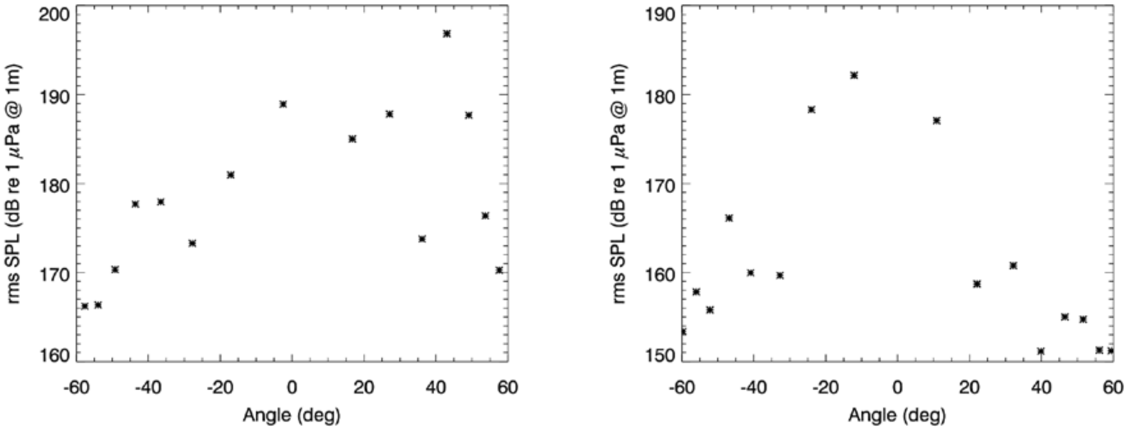


FIGURE 3.66. Kongsberg EA600 single-beam sonar rms SPL source level versus angle off vertical (straight down) operating at 18 kHz (left) and 200 kHz (right). Data were captured as the *Synergy* sailed directly over the recorders. Please see text regarding missing zero degree data points.

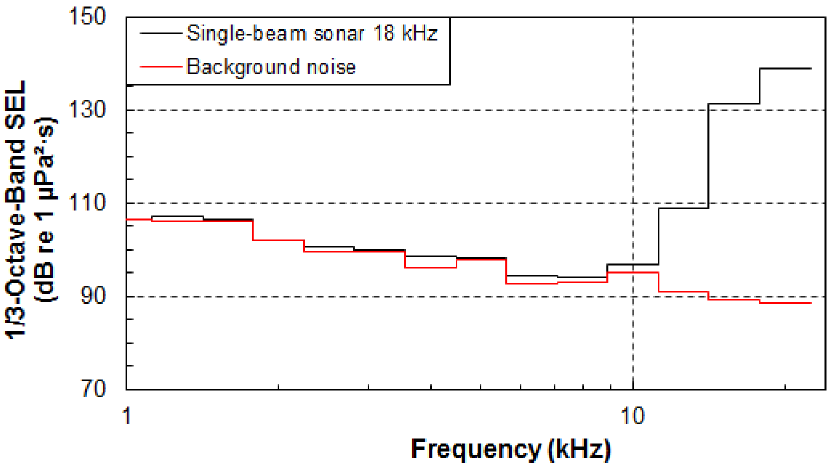


FIGURE 3.67. Kongsberg EA600 single-beam sonar (18 kHz) 1/3-octave band SEL over a 25-ms time window. Data were averaged from the four highest-amplitude 18 kHz pulses, measured at 37–45 m (40 – 49 yd) slant range. The corresponding average band levels of background noise from the four preceding 25-ms windows are shown in red.

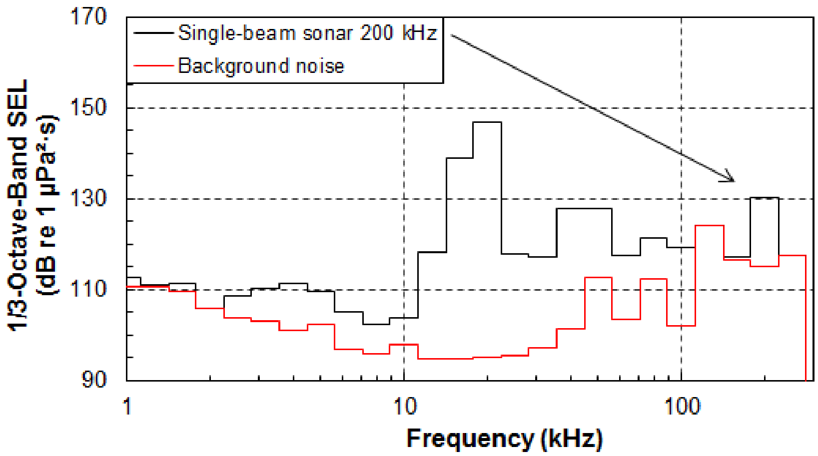


FIGURE 3.68. Kongsberg EA600 single-beam sonar (200 kHz) 1/3-octave band SEL over a 30-ms time window. Data were averaged from the three highest-amplitude 200 kHz pulses, measured at 37–40 m (40 – 44 yd) slant range. The corresponding average band levels of background noise from the three preceding 30-ms windows are shown in red. Sonar levels in frequency bands below 125 kHz exceed background levels because of concurrent 18-kHz single-beam and 50 kHz Furuno FE-700 echosounder pulses and their harmonics.

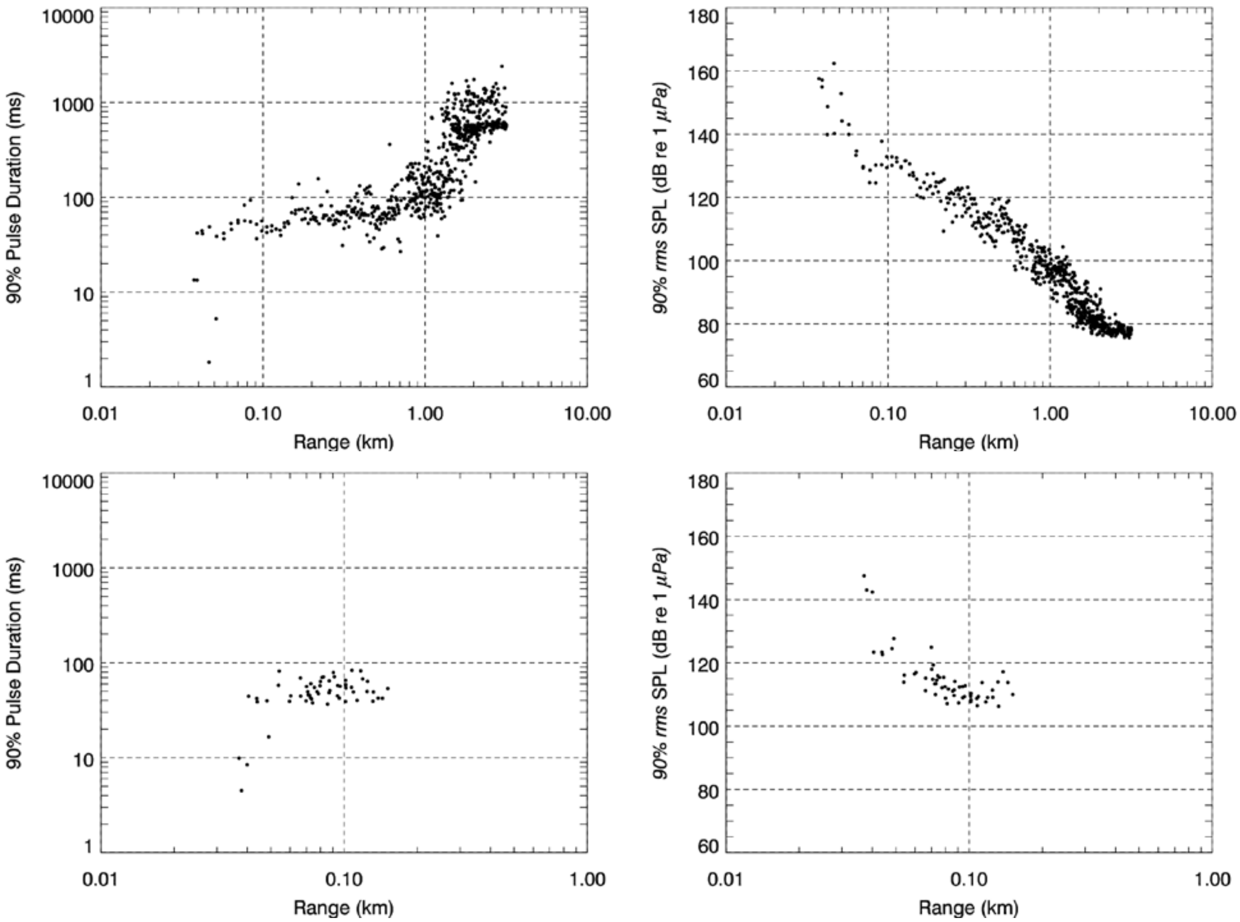


FIGURE 3.69. Kongsberg EA600 single-beam sonar 90% pulse duration and rms SPL as a function of range for 18 kHz (top) and 200 kHz (bottom) pulses. Single-beam pulses occurred every 3.33 seconds.

Kongsberg High Precision Acoustic Positioning (HiPAP) 500

Peak SPL, 90% rms SPL and SEL for each 22/23-kHz and 21/21.5-kHz HiPAP pulse during the DP portion of the test were computed from all available acoustic data. The three recorders were operational during the 22/23-kHz pulses but the memory on the AMAR had been filled by the time the 21/21.5-kHz pulses occurred. Data from the more sensitive TC4032 hydrophones on the OBH recorders were used in the analysis. HiPAP pulses occurred once every 3 seconds for the 22/23-kHz frequency mode and once every 0.94 seconds for the 21/21.5-kHz frequency mode. The HiPAP transmits on a ±100° beam under the ship.

Fig. 3.70 shows the sound level versus slant range plot from both frequency modes of the HiPAP unit. Data for the 22/23 kHz HiPAP were band pass filtered from 20 to 24 kHz, while the narrower-band 21/21.5 kHz pulses were filtered from 20 to 23 kHz. Table 3.22 shows ranges to the 190 to 120 dB re 1 μPa rms SPL thresholds which were computed from the 90th percentile empirical curve fits to the SPL versus range data.

Waveform and spectral density plots of HiPAP pulses at 22/23 kHz and 21/21.5 kHz are shown in Figures 71 and 72, respectively. In the spectrum plots, background noise from time windows immediately preceding the pulses is plotted in red for comparison. Fig. 3.73 shows spectrograms of HiPAP pulses from both operating frequencies measured on the closest recorders.

Figures 74 and 75 show averaged 1/3-octave band levels from the 22/23- and 21/21.5-kHz HiPAP pulses, respectively. Ten 22/23-kHz pulses from the AMAR measurements were averaged; the ten 21/21.5 kHz pulses were taken from OBH A. Average background noise levels from preceding time windows are shown on the plots for comparison.

Third-octave band source levels were estimated by back-propagation of filtered levels assuming 20log*R* (spherical) spreading and estimated absorption loss at the 1/3-octave band center frequencies (Francois and Garrison 1982: see methods section Sound Attenuation with Range). For the 22/23 kHz pulses measured on the AMAR, source levels in the 20 and 25 kHz bands are estimated to be 172.5 and 172.1 dB re 1 μPa^2s at 1 m (1.1 yd), respectively. For 21/21.5-kHz pulses, the highest measurable band was the 20 kHz band, with an estimate source level of 162.4 dB re 1 μPa^2s at 1 m (1.1 yd).

Fig. 3.76 shows how rms pulse duration varied with range for the 22/23- and 21/21.5-kHz HiPAP pulses, respectively. The plots show that the average rms pulse duration increased with range.

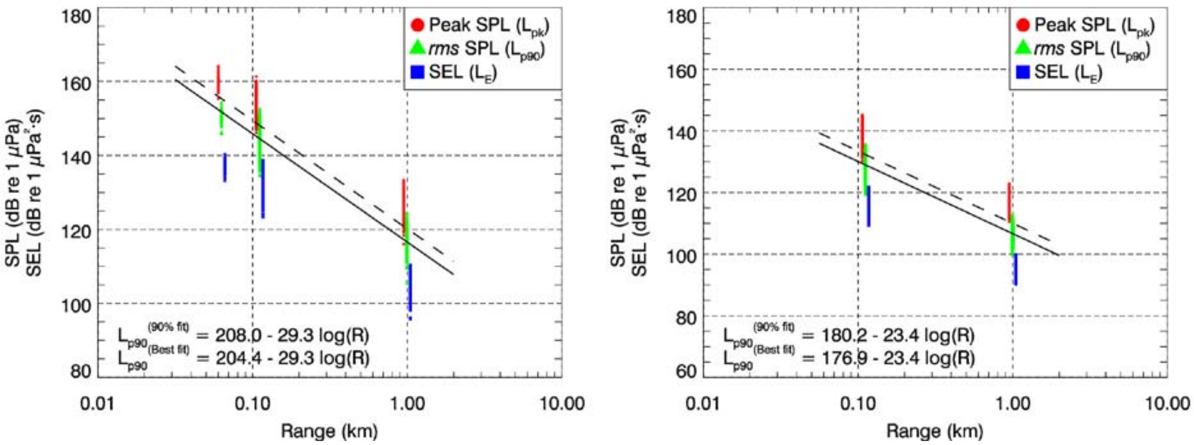


FIGURE 3.70. Kongsberg HiPAP 500 peak SPL, rms SPL, and per-pulse sound SEL versus slant range at the measurement location for the 22/23 kHz (left) and 21/21.5 kHz (right) modes. Solid line is best fit of the empirical function to SPL_{rms90} values. Dashed line is the best-fit adjusted to exceed 90% of the SPL_{rms90} values. Acoustic data were band-pass filtered before calculating sound levels; 20–24 kHz (left) and 20–23 kHz (right). Peak SPL and SEL are offset slightly in range to avoid overlap in this display.

TABLE 3.22. Kongsberg HiPAP 500 threshold radii for the 22/23 kHz and 21/21.5 kHz modes at the measurement location as determined from SPL_{rms90} versus distance data in Fig. 3.70.

SPL_{rms90} Threshold (dB re 1 μPa)	22/23 kHz		21/21.5 kHz	
	Best-Fit Line Radius (m)	90th Percentile Radius (m)	Best-Fit Line Radius (m)	90th Percentile Radius (m)
190	3*	4*	-	-
180	7*	9*	1**	1**
170	15*	20*	2**	3**
160	33*	44*	5**	7**
150	72	96	14**	20**
140	160	210	38**	52**
130	350	460	100**	140
120	770	1000	270	370

*Extrapolated beyond minimum measured range of 63 m.

**Extrapolated beyond minimum measured range of 111 m.

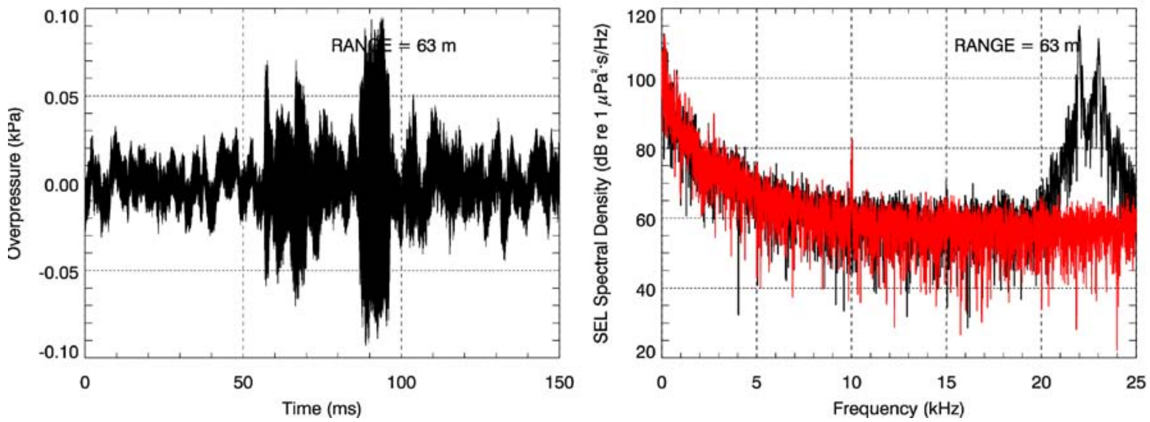


FIGURE 3.71. Kongsberg HiPAP 500 waveform (left) and SEL spectral density (right) over 150 ms for dual 22 and 23 kHz pulses at 63 m (69 yd) slant range. Background noise from the preceding 150 ms is shown in red for comparison. Reverberation energy from the 18-kHz SBE is also apparent here.

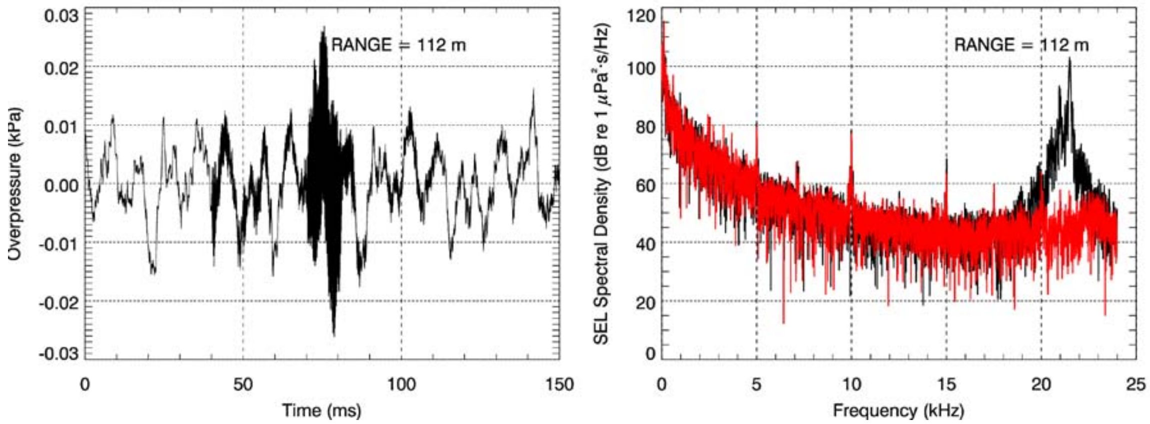


FIGURE 3.72. Kongsberg HiPAP 500 waveform (left) and SEL spectral density (right) over 150 ms for dual 21 and 21.5 kHz pulses at 112 m (123 yd) slant range. Background noise from the preceding 150 ms is shown in red for comparison.

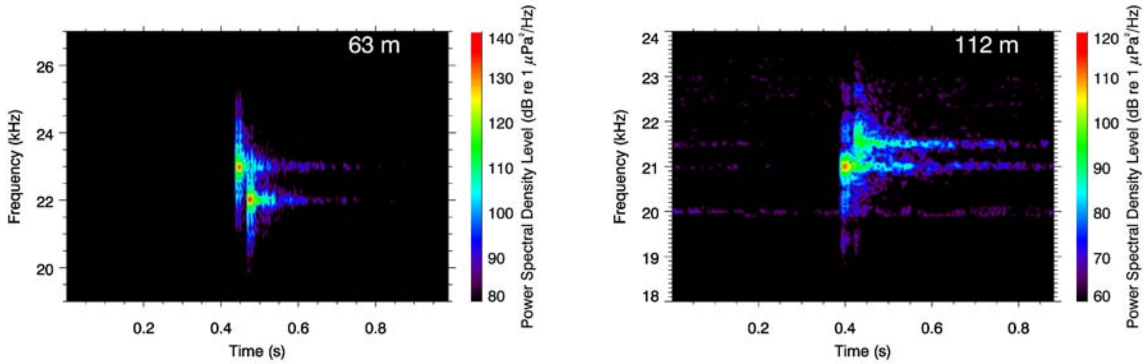


FIGURE 3.73. Kongsberg HiPAP 500 spectrograms for 22/23-kHz (left) and 21/21.5-kHz (right) pulses measured on the AMAR and OBH recorders at 63 and 112 m (69 and 123 yd) slant range, respectively. 687.5 ksps, 8192-pt FFT (left) and 48 ksps, 1024-pt FFT (right), 87.5% overlap, Hanning window.

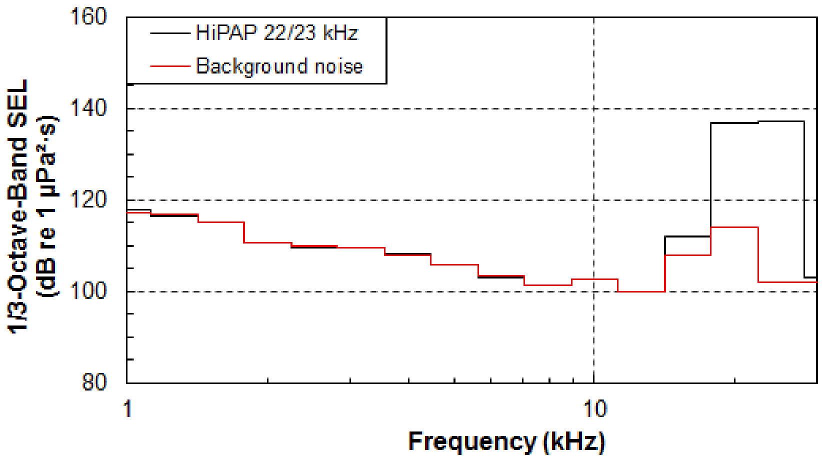


FIGURE 3.74. Kongsberg HiPAP 500 22/23-kHz 1/3-octave band SEL over 35-ms time windows. Data were averaged from 10 pulses measured at 63 m (69 yd) slant range. The corresponding band levels of background noise from the preceding 35-ms windows are shown in red.

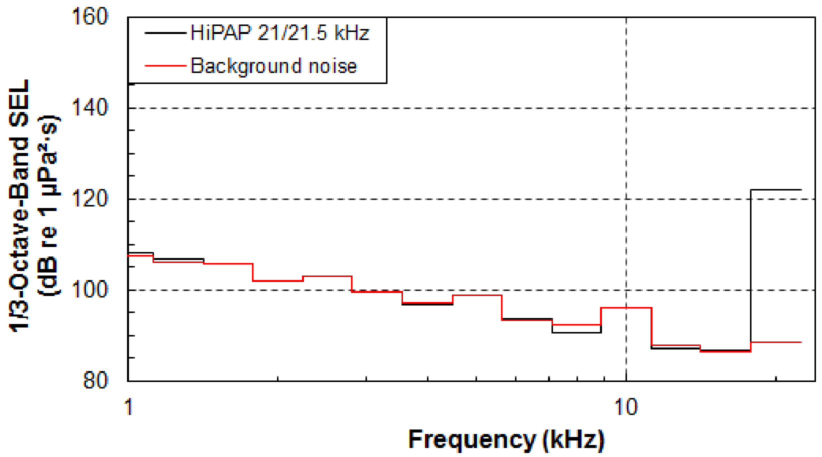


FIGURE 3.75. Kongsberg HiPAP 500 21/21.5-kHz 1/3-octave band SEL over 35-ms time windows. Data were averaged from 10 pulses measured at 112 m (123 yd) slant range. The corresponding band levels of background noise from the preceding 35-ms windows are shown in red.

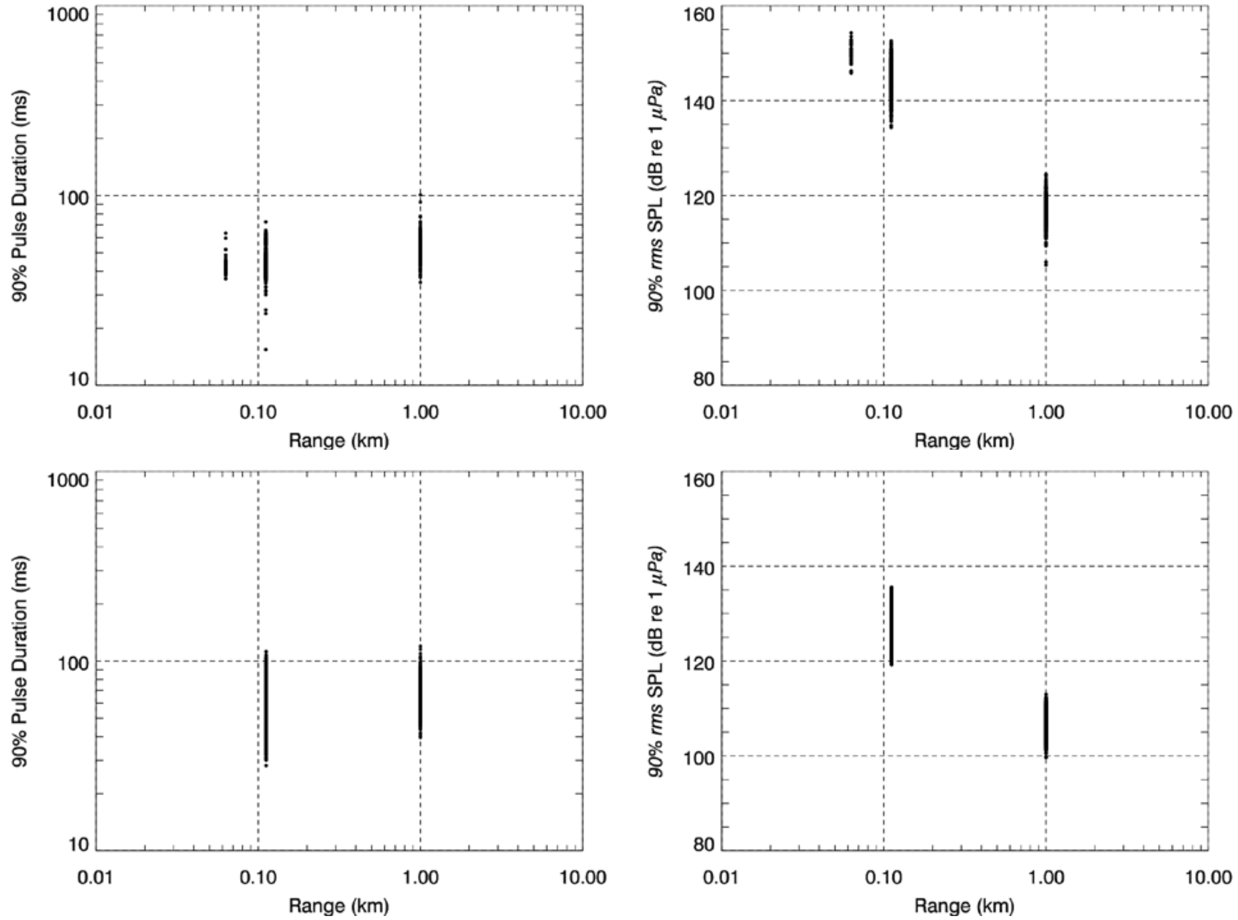


FIGURE 3.76. Kongsberg HiPAP 500 90% pulse duration and rms SPL as a function of range for 22/23-kHz (top) and 21/21.5-kHz (bottom) pulses. HiPAP pulses occurred every 3 and 0.94 seconds for the 22/23-kHz and 21/21.5-kHz frequency modes, respectively.

Vessel Noise (Dynamic Positioning) - No Coring

SPLs were computed for vessel self-noise on the *Synergy* while in DP on all three recorders. These levels were computed in consecutive 1-second time windows and represent continuous noise levels as opposed to the impulsive levels presented for other sources in this report. Fig. 3.77 presents the rms levels versus range for the *Synergy* vessel noise while in DP mode without coring, as well as the best-fit and 90th percentile trend lines and the equations thereof. Data presented in these plots were recorded from the higher sensitivity TC4032 hydrophones on the OBH recorders and the TC4014 hydrophone on the AMAR. The ranges to the sound level thresholds of 160 to 120 dB re μPa (rms) for the *Synergy* in DP without coring are listed in Table 3.23.

While in DP, noise levels and the frequency of the *Synergy's* thrusters fluctuated with time, whereas noise levels and frequencies of the vessel's engines, generator sets, and other equipment were constant. The frequency of the *Synergy's* thrusters fluctuated between 110 and 140 Hz so a band pass filter between 110 and 140 Hz was applied to calculate the variability in thruster sound levels. Fig. 3.78 shows the broadband and band pass filtered (110-140 Hz) time evolving rms SPLs for the DP test. Broadband levels, which include sounds from diesel generators, DP thrusters, and other equipment, fluctuate by up to 5 dB over time whereas levels from the DP thrusters fluctuate by up to 12 dB. Fig. 3.79 shows a spectrogram during the same time period that illustrates the constant generator and equipment tones and changing frequency tones from the thrusters. The constant-frequency tones are louder than the thruster noise, indicating that the thrusters are not the loudest sound source.

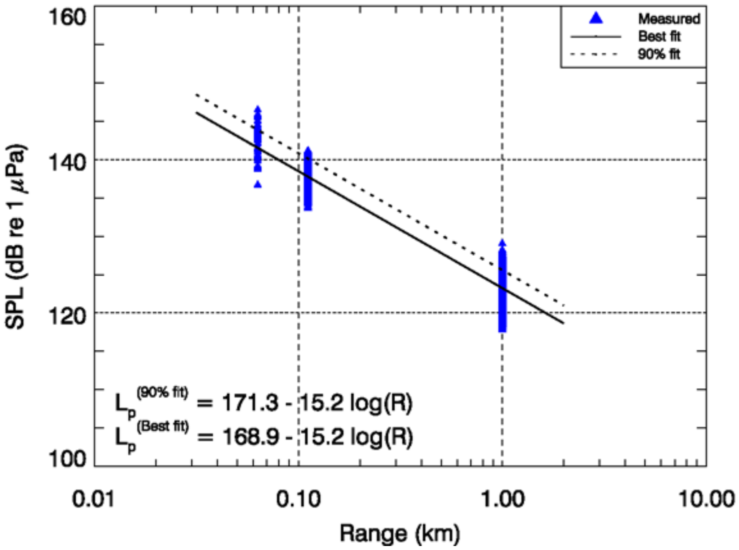


FIGURE 3.77. *Synergy* rms SPL versus slant range while in DP mode without coring. Solid line is best fit of the empirical function to SPL values. Dashed line is the best-fit adjusted to exceed 90% of the SPL values.

TABLE 3.23. *Synergy* threshold radii for DP without coring at the measurement location as determined from SPLrms versus distance data in Fig. 3.77.

SPL_{rms} Threshold (dB re 1 μPa)	Best-Fit Line Radius (m)	90th Percentile Radius (m)
170	1*	1*
160	4*	6*
150	18*	25*
140	79	110
130	360	510
120	1600**	2300**

*Extrapolated beyond minimum range of 63 m.

**Extrapolated beyond maximum measured range of 1 km.

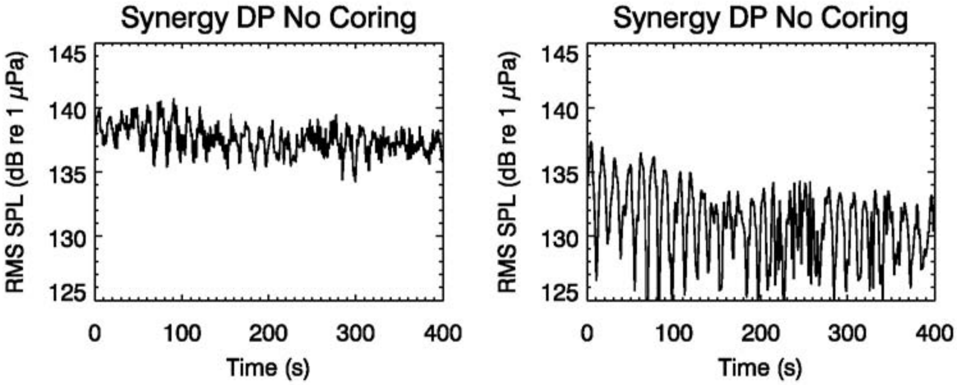


FIGURE 3.78. *Synergy* rms SPL versus time capturing vessel DP recorded at 111 m (121 yd) slant range. Broadband (left) and band pass filtered between 110 and 140 Hz (right) in order to capture the dynamic positioning thruster fundamental frequency in the presence of diesel generators in the lower frequency spectrum.

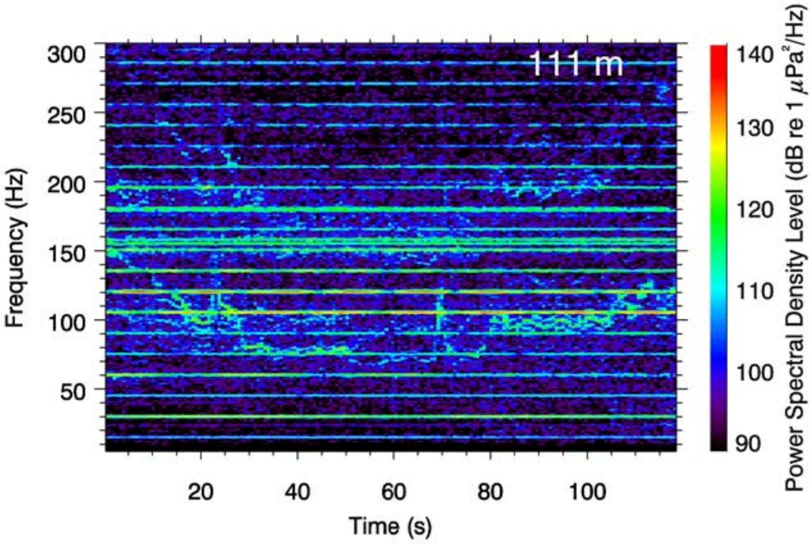


FIGURE 3.79. Low frequency spectrogram of *Synergy* while on DP recorded at 111 m (121 yd) slant range. Unstable thruster tonal frequencies can be seen between 70 and 200 Hz. 48 ksps, 65536-pt FFT, 50% overlap, Hanning window.

Vessel Noise (Dynamic Positioning) During Coring

SPLs were computed for vessel self-noise on the *Synergy* while coring in DP mode on just the two TC4032 channels of the OBH recorders. The AMAR was not used in this measurement because its memory had been filled by the time the test was carried out. Continuous sound levels were computed in consecutive 1-second time windows.

Fig. 3.80 presents the rms levels versus range for the *Synergy* vessel noise while in DP mode with coring, as well as the best-fit and 90th percentile trend lines and the equations thereof. The ranges to the sound level thresholds of 160 to 120 dB re µPa (rms) for the *Synergy* in DP during coring are listed in Table 3.24.

Fig. 3.81 shows the broadband and band pass filtered (between 110 and 140 Hz for the thruster levels) time-evolving rms SPLs for the DP test during coring. Fig. 3.82 shows the spectrogram from the same time period that illustrates the changing tonal frequency as the thrusters are used for DP. The spectrogram shows constant-frequency tones that are louder than the thruster noise, indicating that the thrusters are not the loudest sound source while the *Synergy* is in DP.

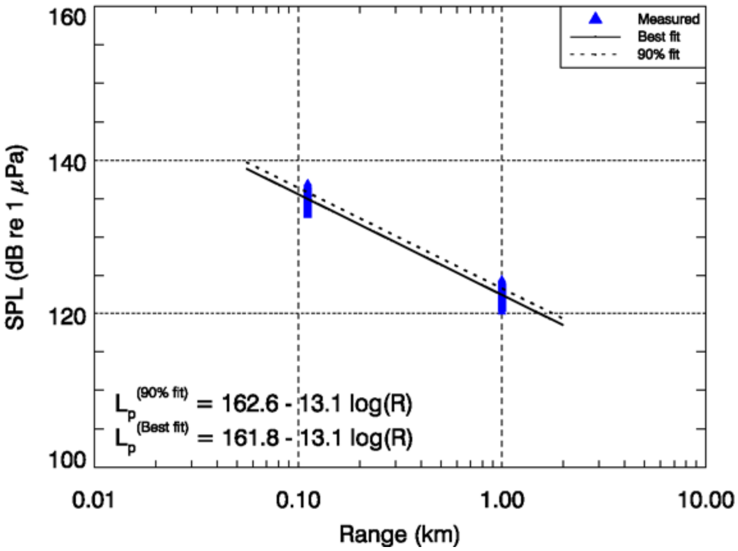


FIGURE 3.80. *Synergy* rms SPL versus slant range while coring in DP mode. Solid line is best fit of the empirical function to SPL values. Dashed line is the best-fit adjusted to exceed 90% of the SPL values.

TABLE 3.24. *Synergy* threshold radii for DP during coring at the measurement location as determined from SPLrms versus distance data in Fig. 3.80.

SPL_{rms} Threshold (dB re 1 µPa)	Best-Fit Line Radius (m)	90th Percentile Radius (m)
160	1*	2*
150	8*	9*
140	46*	53*
130	270	300
120	1500**	1800**

*Extrapolated beyond minimum range of 63 m.

**Extrapolated beyond maximum measured range of 1 km.

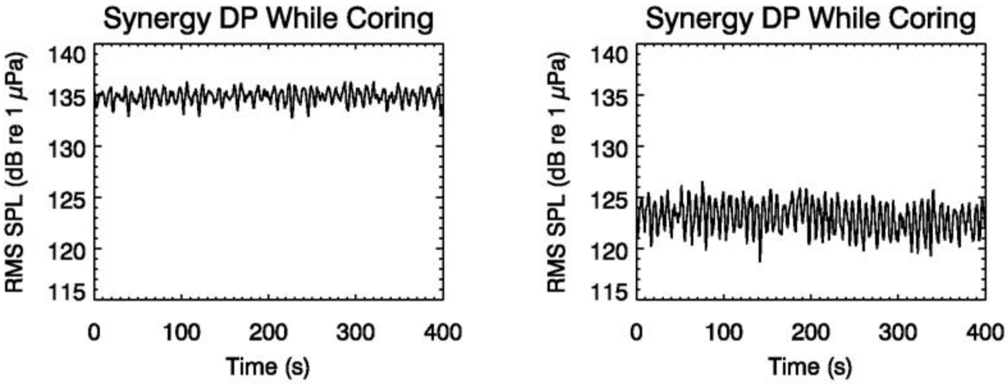


FIGURE 3.81. *Synergy* rms SPL versus time plot capturing vessel DP during coring. Levels are from recordings at 111 m (121 yd) slant range. Broadband (left) and band pass filtered between 110 and 140 Hz (right) in order to capture the dynamic positioning thruster fundamental frequency in the presence of diesel generators in the lower frequency spectrum.

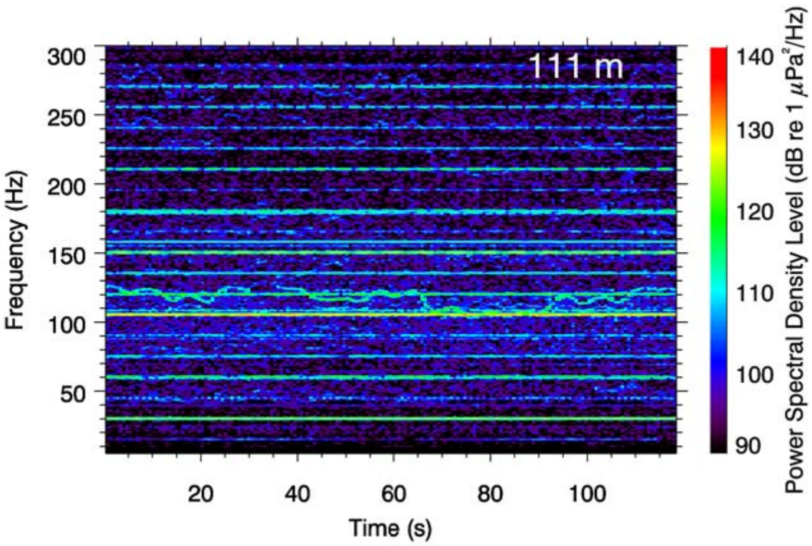


FIGURE 3.82. Low frequency spectrogram of *Synergy* while on DP performing coring operations recorded at 111 m (121 yd) slant range. Unstable thruster tonal frequencies can be seen between 110 and 140 Hz. 48 ksps, 65536-pt FFT, 50% overlap, Hanning window.

Vessel Noise – M/V Fugro *Synergy*

SPLs were computed for vessel self-noise of the *Synergy* as it transited past OBH recorder A, 100 m (109 yd) from the coring site. Data presented in this section were recorded from the higher sensitivity TC4032 hydrophone. Continuous noise levels were computed in consecutive 1-second time windows and were low-pass filtered at 10 kHz to remove sounds from the single-beam sonar. Fig. 3.83 shows sound levels plotted as a function of time to show the evolution of level increase and decrease as the vessel passed the OBH. Fig. 3.84 presents the rms levels versus range for the *Synergy* vessel noise transiting at 4.5 kts, as well as the best-fit and

90th percentile trend lines and the equations thereof. The ranges to the sound level thresholds of 160 to 120 dB re µPa (rms) for the *Synergy* travelling at 4.5 kts are listed in Table 3.25.

Spectrogram and power spectral density plots for CPA (37 m slant range) are shown in Fig. 3.85 and Fig. 3.86, respectively. The spectrogram clearly shows the expected Lloyd Mirror interference pattern as the *Synergy* passed the OBH. Three pulses from the OBH's acoustic release are visible in the spectrogram at 8 kHz around the CPA. T he acoustic release was likely triggered by the EA600 single-beam sonar, which is also responsible for the peak at 18 kHz in the power spectral density plot.

Fig. 3.87 shows a contour plot of 1/3-octave band levels, versus range and frequency for the *Synergy* transiting at 4.5 kts. The contour plot shows the spectral distribution of sound energy versus range, and also shows which frequencies dominated sound propagation at the test site. Sound levels at frequencies at 30 Hz and between 90 and 400 Hz were highest near the vessel. Sounds at frequencies of 30 and 100 Hz showed the strongest propagation with range. The high 30 Hz levels arise from the *Synergy*'s engines and generators, which operate at 1800 rpm.

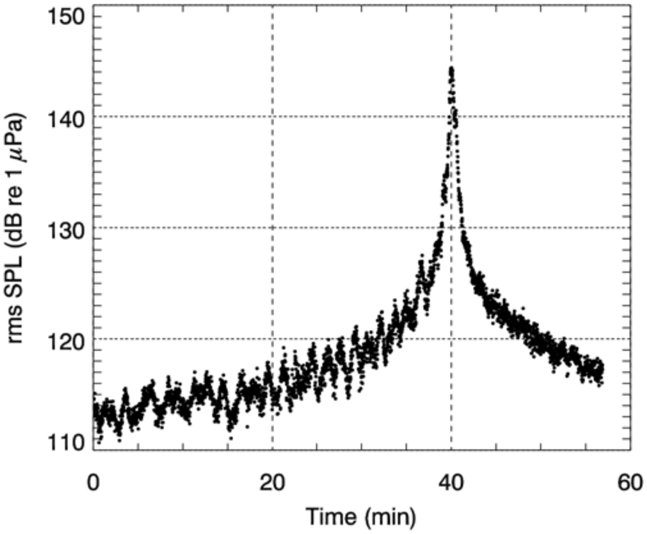


FIGURE 3.83. *Synergy* broadband rms SPL as a function of time as the vessel traversed the 7 km (4 mi) track line at 4.5 kts. CPA was 37 m (40 yd) slant range.

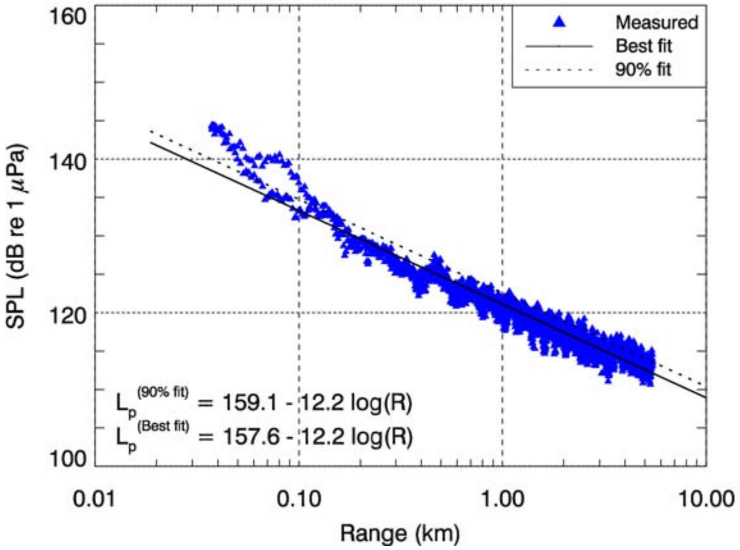


FIGURE 3.84. *Synergy* rms SPL versus slant range for transiting past OBH recorder A at 4.5 kts. Solid line is best fit of the empirical function to SPL values. Dashed line is the best-fit adjusted to exceed 90% of the SPL values. The data were low pass filtered at 10 kHz to avoid high frequency sources increasing the SPLs.

TABLE 3.25. *Synergy* threshold radii for the transiting at 4.5 kts at the measurement location as determined from SPL versus distance data in Fig. 3.84.

SPL_{rms} Threshold (dB re 1 μPa)	Best-Fit Line Radius (m)	90th Percentile Radius (m)
160	1*	1*
150	4*	6*
140	28*	37
130	190	250
120	1200	1600

*Extrapolated beyond minimum measurement range of 37 m

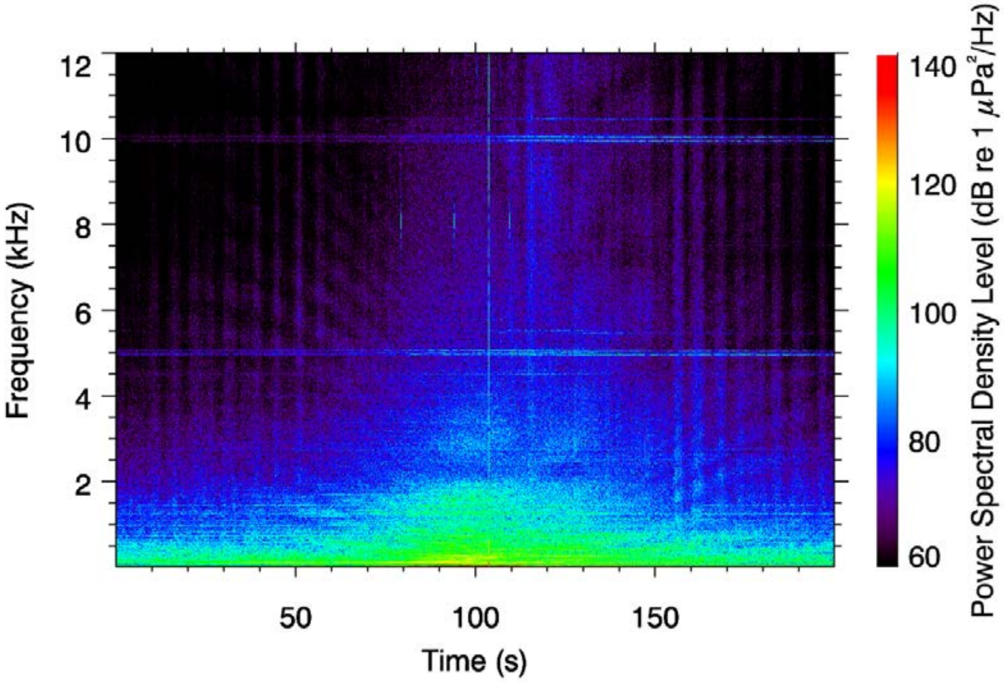


FIGURE 3.85. *Synergy* vessel noise spectrogram at CPA (37 m slant range). The *Synergy* was travelling at 4.5 kts. 48 ksps, 8192-pt FFT, 87.5% overlap Hanning window. The 5 and 10 kHz sounds are from a continuous, though unidentified source.

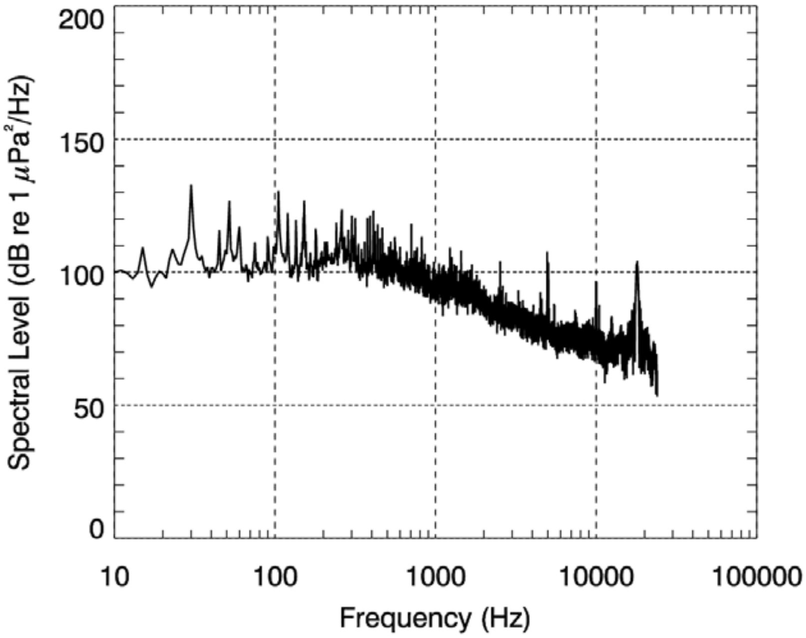


FIGURE 3.86. *Synergy's* average unfiltered power spectral density (PSD) from five 1-s windows around the 37 m CPA for transiting at 4.5 kts. The peak at 18 kHz is due to the concurrently operating EA600 single-beam sonar.

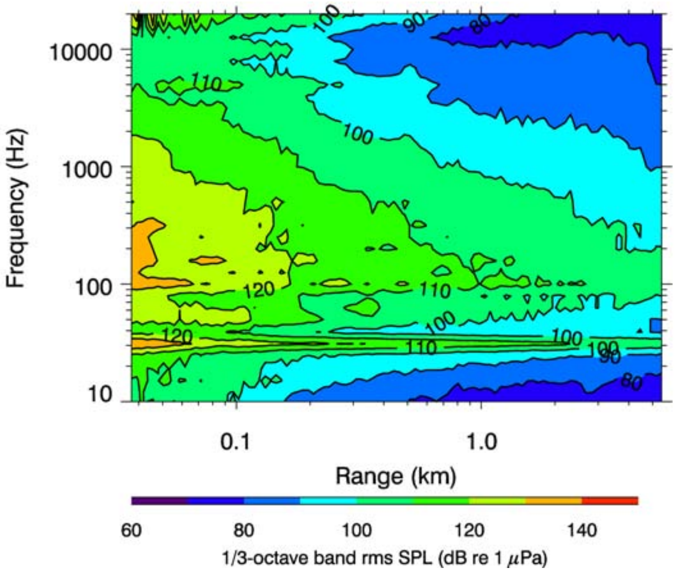


FIGURE 3.87. *Synergy* vessel noise third-octave band levels as a function of range and frequency for transiting at 4.5 kts. High levels at 30 Hz are due to the vessel's generators operating at 1800 rpm.

Discussion

Airguns

Sound Levels vs Range

Sound levels measured from the airguns between 4 and 5.3 km (2.5 and 3.3 mi) range showed two different trends (Fig. 3.9 and Fig. 3.16). Levels were about 3 dB lower when the source was at the south end of the line compared to when it was at an equivalent distance mid-line. The two track lines were run in opposite directions so the effect was not due to the vessel obstructing sound propagation.

Fig. 3.88 shows spectrograms from pulses measured at 5.3 km (3.3 mi) distance before and after CPA. The spectrograms show five modes are supported 5.3 km (3.3 mi) either side of CPA, but normal mode propagation is weaker between the south end of the line and the OBH recorders. Since the difference in sound levels was only observed at ranges between 4 and 5.3 km (2.5 and 3.3 mi), the difference in modal propagation must be attributed to environmental differences at the southern-most 1.3 km (0.8 mi) of the line.

Fig. 3.89 shows the bathymetry over the track line. The water depth was about 40 m (44 yd) at the south end of the line and about 36 m (39 yd) at the equivalent distance mid-line (10 km [6 mi]from the south end). During modal propagation, acoustic waves reflect off the surface and bottom multiple times and incur energy loss at each reflection. In deeper water, modes propagate at shallower angles and therefore interact with the surface and bottom fewer times to reach a given range. Though it was deeper around the south end of the line, modal propagation was weaker at this location and so the effect of water depth can be ruled out as an environmental factor causing the difference in sound levels.

The seabed must have been more acoustically absorptive at the south end of the line to make up for the depth effect. A softer bottom having lower bottom sound speed would increase energy loss at each reflection. Therefore, the differences in sound levels measured at these ranges can be attributed to site-specific geoacoustic properties, where the seabed at the southern-most 1.3 km (0.8 mi) of the line is more absorptive and has a lower sound speed compared to the rest of the line.

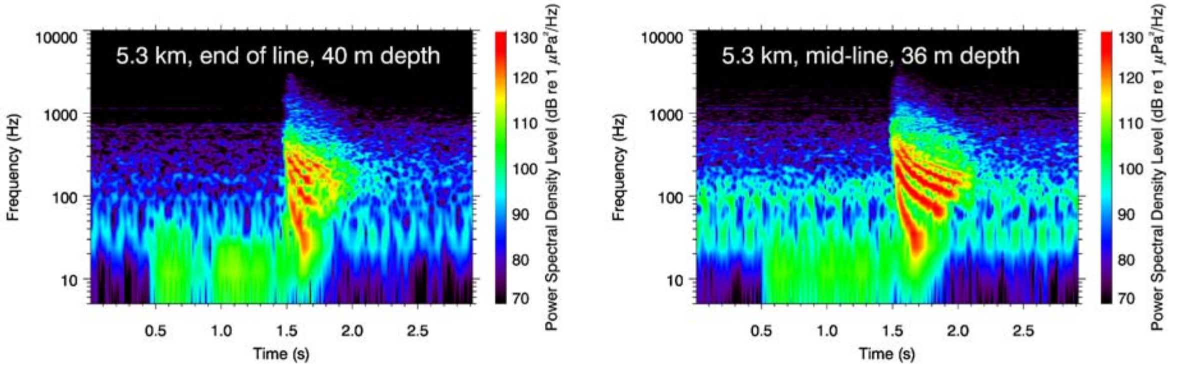


FIGURE 3.88. 40 in^3 airgun array pulse spectrograms measured at 5.3 km (3.3 mi) range as the array approached (left) and departed (right) the OBH recorder. The approach spectrogram shows a pulse from when the airguns were at the south end of the line. 48 ksps, 8192-pt FFT, 87.5% overlap, Hanning window.

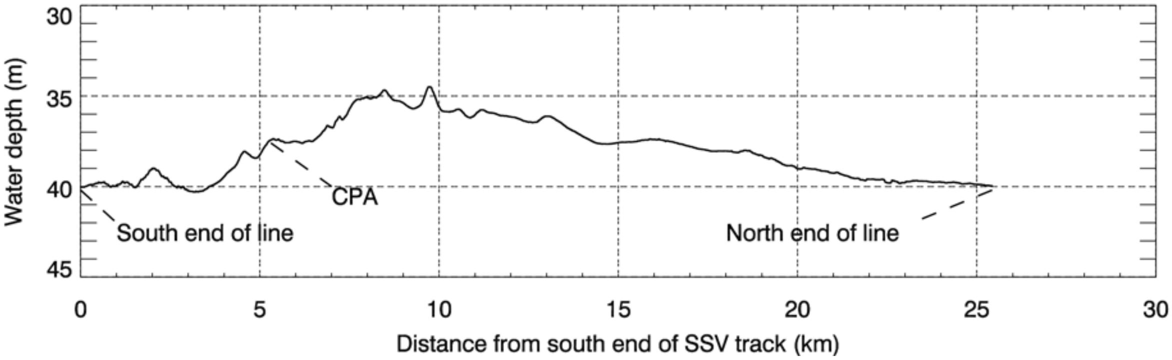


FIGURE 3.89. Bathymetry along the *Duke's* airgun track line.

Pulse Duration versus Range

The trend of rms pulse duration versus range was continuous at ranges beyond 1 km (0.6 mi), but had a sawtooth trend at closer ranges. This pattern is clearly visible in the 40 in^3 airgun array data (Fig. 3.15) and somewhat visible in the 10 in^3 mini-airgun data (Fig. 3.22).[2] This is a result of the 90% rms metric's sensitivity to the fine structure of pressure waveforms.

Fig. 3.90 shows stacked pressure waveforms from selected 40 in^3 airgun array pulses measured at slant ranges from 34 m to 205 m (37 yd to 224 yd), scaled for display. The pulses have been aligned so the start of the 90% rms time integration window is at 0 seconds, and the end of the 90% rms integration window is indicated with a vertical red line. At ranges less than 150 m (164 yd), the integration window includes the strong direct path arrival and the weaker first bottom multiple (sound that has reflected off the bottom then surface at least once). As range increases, sound reflects off the bottom at shallower angles and incurs less bottom loss, strengthening the bottom multiple relative to the direct path. The path length and arrival time difference for these two paths also decreases, and consequently, the 90% pulse length decreases. At ranges

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[2] The pattern is also visible, though coarsely sampled, for the GeoAcoustics 159D side-scan sonar data (FIGURE 40).

greater than 150 m (164 yd), the second bottom multiple (sound that has reflected off the bottom then surface at least twice) becomes included in the integration window because its relative amplitude has increased. This increases the duration of the integration window.

At farther ranges, the pulse length decreases until the third bottom multiple is included in the integration window. The inclusion of another bottom multiple in the integration window causes a discontinuity in the rms pulse duration trend with range. At ranges beyond 1 km (0.6 mi), the multipath arrivals are so close together in time that the trend with range becomes essentially continuous (Fig. 3.15).

This effect is not as clear in the pulse duration versus range plot for the 10 in^3 mini-airgun results (Fig. 3.22). The mini-airgun signature contains several oscillatory bubble pulses (Fig. 3.18) whereas the 40 in^3 airgun array signature is essentially only composed of a primary peak and inverted surface reflection (Fig. 3.11). Each bottom multiple from the 40 in^3 waveform therefore only contains a single positive and negative pressure pulse. Due to the bubble pulses, each bottom multiple from the 10 in^3 waveform contains several oscillations. The received 10 in^3 waveforms therefore contain many more oscillations, and consequently there is more scatter in the rms pulse duration. There trend is not completely masked by scatter because the groups of bubble pulse oscillations from the direct path and bottom multiples affect the rms pulse duration in the same way as the single oscillation from the 40 in^3 airgun array.

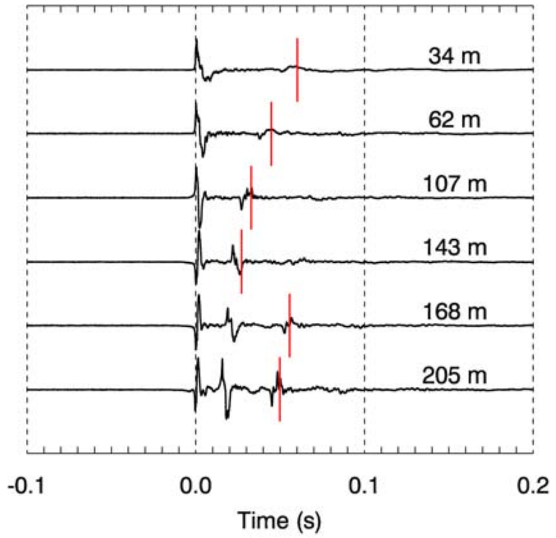

FIGURE 3.90. Stacked waveforms of selected 40 in^3 airgun array pulses. The vertical red lines indicate the end of the 90% rms time integration window. Distances are slant ranges at which the pulses were measured. The waveform amplitudes have been scaled for display.

Comparison of Measured and Pre-Season Radii

Table 3.26 lists the pre-season estimated and in-field measured sound level threshold radii for the *Duke*'s 40 in^3 airgun array and 10 in^3 mini-airgun. The measured radii for the 40 in^3 airgun array were less than the pre-season estimates; the measured radii for the 10 in^3 mini-airgun were more than the pre-season estimates.. The pre-season estimated radii were based on results from a similar underwater acoustics measurement program (see LGL, 2011 for the derivation). The differences between measured and estimated radii are likely due to the following factors: the precautionary 25% increase to estimated radii (for the 40 in^3 airgun array), airgun array geometry, environmental conditions (including water depth, sound speed profile, geoacoustic properties of the seabed, and weather conditions), and the performance of the individual airguns themselves.

Figures 91 and 92 provide summaries of 90th percentile distances to several threshold levels from previous measurements of 40 in^3 airgun arrays and single 10 in^3 airguns (Chorney et al. 2011, Warner et al. 2010, Hannay and Warner, 2009, and Hannay and Warner, 2008). The measurements from Burger (2009) are the most comparable in terms of geographic location and environmental conditions.

TABLE 3.26. Comparison of measurements with pre-season estimated radii for the *Duke's* 40 in^3 airgun array and 10 in^3 mini-airgun.

SPL$_{rms90}$ Threshold (dB re 1 µPa)	40 in^3 airgun array		10 in^3 mini-airgun	
	Pre-season estimated radii (m)	Measured radii (m)	Pre-season estimated radii (m)	Measured radii (m)
190	50	37	10	15*
180	190	130	45	59
160	2250	1500	715	840
120	39000	30000*	24000	29000*

*Extrapolated beyond measurement range

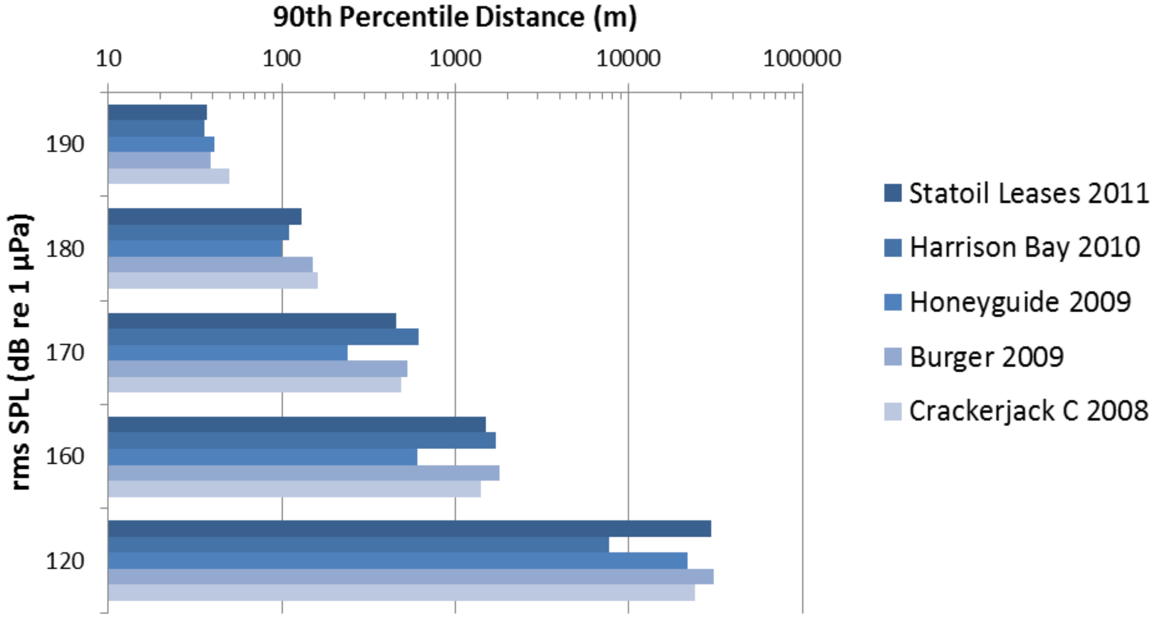

FIGURE 3.91. Distances to sound level thresholds from measurements of 40 in^3 airgun arrays. Distances are from the 90th percentile fits to SPL versus range data.

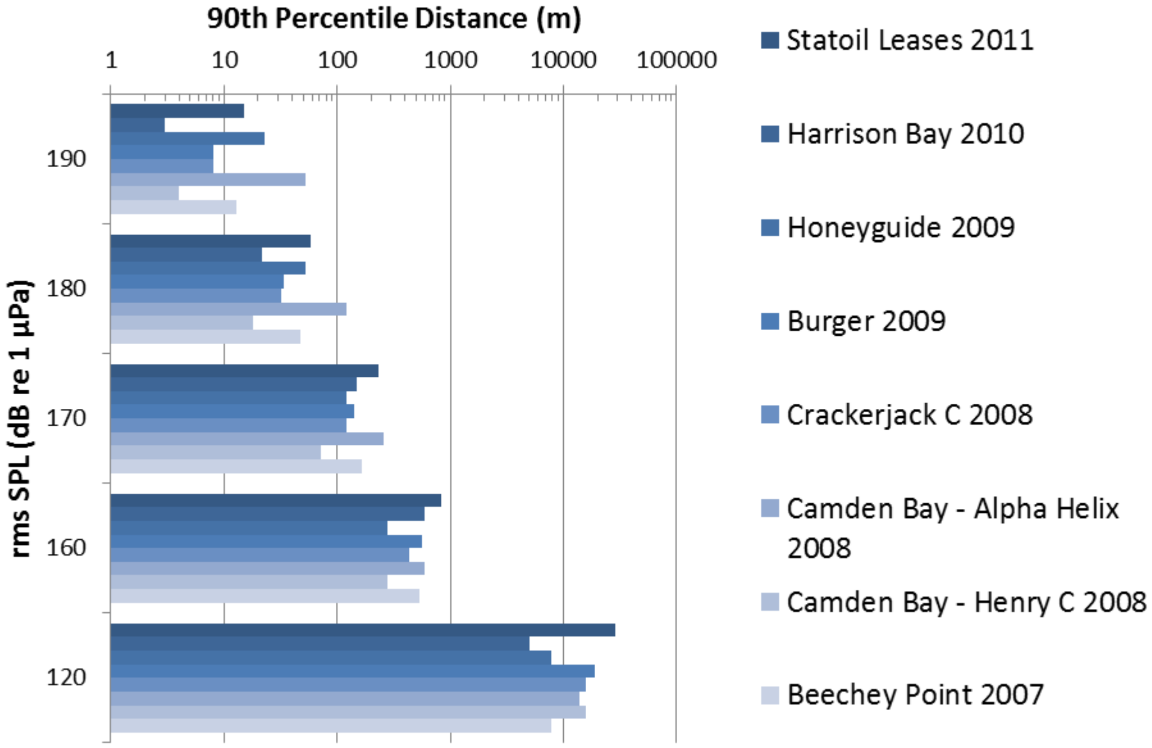

FIGURE 3.92. Distances to sound level thresholds from measurements of 10 in^3 airguns. Distances are from the 90th percentile fits to SPL versus range data.

Variability in SonarDyne Ranger Pro USBL Beacon Levels versus Range

The variability in the SonarDyne Ranger Pro USBL beacon sound level versus range data between approximately 100 m and 500 m (109 and 547 yd; Fig. 3.52) is partly due to the sensitivity of the rms metric to pulse waveform structure. Fig. 3.93 shows two consecutive waveforms of in-beam pulses measured at similar range and the cumulative pulse SELs used for the 90% rms integration time window calculations. The pulse pressures are lower for the first pulse, but this alone does not account for the 10.5 dB difference in rms SPL. There is more reverberation relative to the main pulse in the first waveform. This causes a larger integration time window and therefore lowers the rms SPL (see Equation 5).

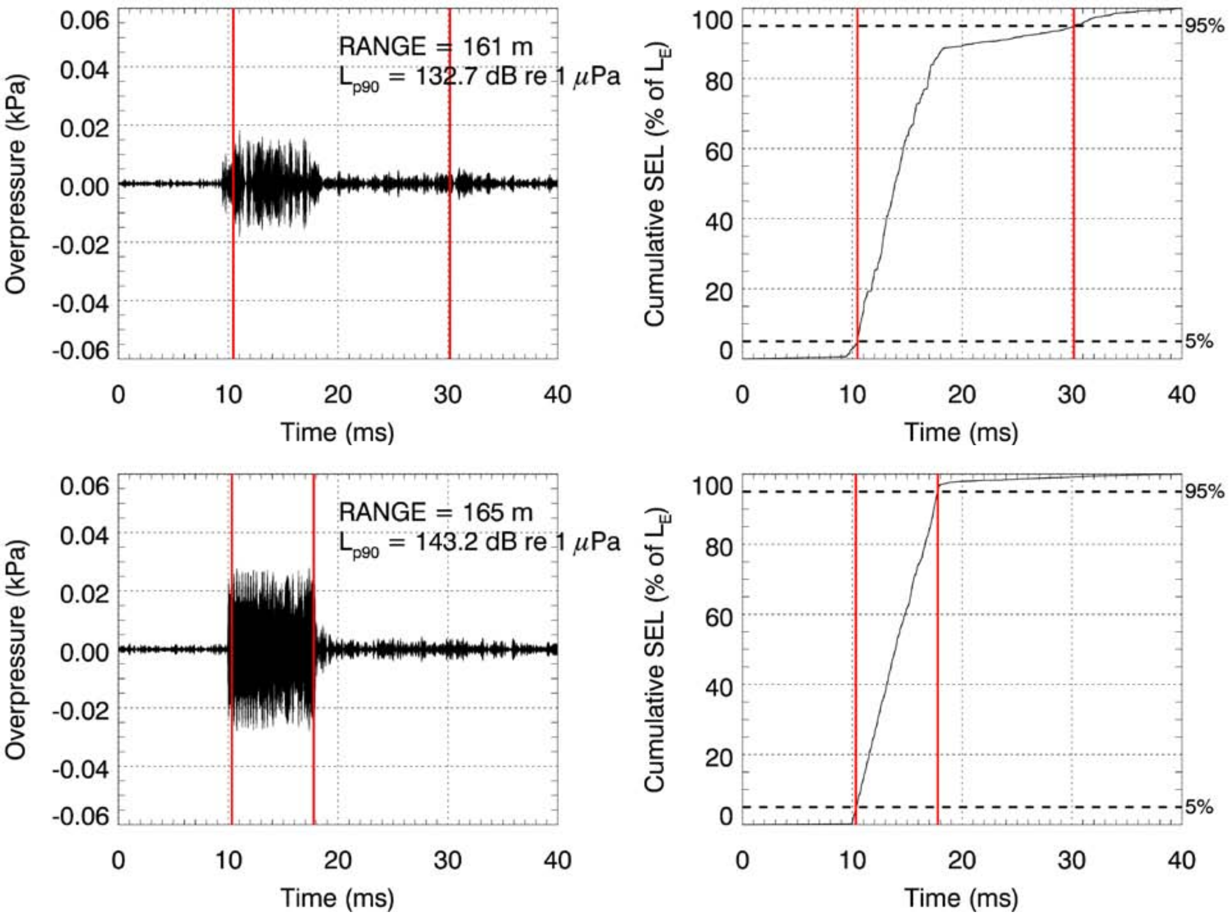

FIGURE 3.93. Two consecutive SonarDyne Ranger Pro USBL beacon in-beam pulse waveforms and corresponding cumulative pulse SEL. Pulses are from measurements at 161 m (176 yd; top) and 165 m (180 yd; bottom) slant range. Vertical red lines indicate the start and end times of the 90% rms integration time window.

Vessels

Source Levels

Source levels for vessel transit noise were calculated from acoustic recordings taken from measurements at less than 200 m (219 yd) range. The levels at these distances had to be adjusted to the standard reference range of 1 m that is used for source levels. The adjustment is referred to as "back-propagation." The common practice is to apply a back propagation correction which assumes that the sound waves propagate uniformly away from the source in all directions and do not interact with the surface or bottom. Such a condition leads to the simple "spherical-spreading loss" correction factor of 20 times the logarithm of measurement distance in meters, or 20log*R*. The spherical loss approximation was applied to 1/3-octave bands centered at 5 kHz and higher, however, the approximation is generally not valid for lower frequencies especially in shallow water conditions.

For 1/3-octave bands centered below 5 kHz, we applied a numerical sound propagation model to back-propagate the levels. The model fully accounts for both water bottom and water surface reflections. It was used to compute transmission loss in 1/12-octave bands and the results were averaged in 1/3-octave bands to apply to the 1/3-octave band received levels.

The model requires several input parameters: geoacoustic properties of the seabed, source depth, and water sound speed profile. The geoacoustic properties of the seabed were inverted from acoustic measurements of the 40 in^3 airgun array. The geoacoustic model parameters were adjusted until modelled transmission loss matched measured levels up to ranges of approximately 2 km (1.2 mi). The resulting geoacoustic model inputs used in back-propagation are listed in Table 3.27. The water sound speed profiles used in the model for the *Duke* and *Synergy* source levels were those of the measured profiles at the time of their respective tests (Fig. 3.8 and Fig. 3.61).

TABLE 3.27. Geoacoustic profile used in back-propagation for calculating source levels of the *Duke* transiting. The propagation model samples the geoacoustic profile and linearly interpolates values by depth.

Depth (mbsf)	Density (g/cm^3)	Compressional Speed (m/s)	Compressional Attenuation (dB/λ)	Shear Speed (m/s)	Shear Attenuation (dB/λ)
0	1.5	1700	0.1	110	2.0
200	1.8	1850	0.2	110	2.0
450	1.8	1850	0.2	110	2.0

The acoustic source depth of the vessels was estimated based on propeller depth, according to the procedure of Wright and Cybulski (1983), where the source of radiated noise was assumed to be at a point midway between the shaft and the top of the propeller disk. The acoustic source depths of the *Duke* and *Synergy* were estimated to be 3.6 and 4.2 m (4 and 4.5 yd), respectively.

The 1/3-octave band source levels for the *Duke* and *Synergy* transiting at 4.5 kts are shown in Fig. 3.94. The corresponding broadband source levels are 182.6 and 173.8 dB re 1 µPa at 1 m for the *Duke* and *Synergy*, respectively. These source levels are suitable as input for computer models to predict received levels for the vessels transiting in different environments.

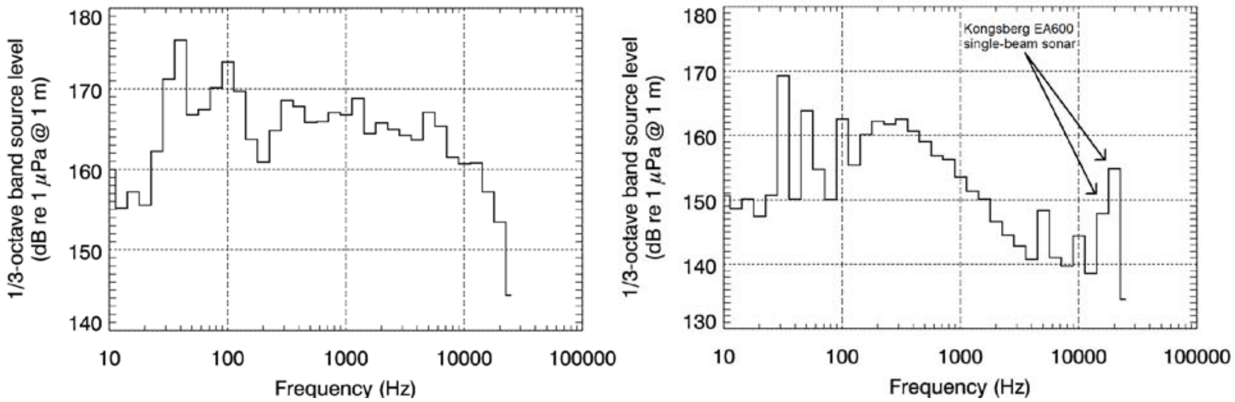

FIGURE 3.94. *Duke* (left) and *Synergy* (right) 1/3-octave band rms SPL source levels for transiting at 4.5 kts. Source depths used in back-propagation were 3.6 and 4.2 m (4 and 4.5 yd) for the *Duke* and *Synergy*, respectively.

Comparison of Synergy Levels to Previous Measurements

Measurements of *Synergy* vessel noise were conducted for transiting and coring operations during 4-5 April 2011 by RPS and Seiche Measurements Ltd. (RPS and Seiche Measurements Ltd., 2011). The study was conducted in the South China Sea, with water depth ranging from 45 to 47 m (49 to 51 yd). A four element linear hydrophone array was towed behind the *Synergy* which was connected to an onboard data processing unit. The hydrophones were sensitive to frequencies between 75 Hz and 30 kHz, with nominal sensitivity -157 dB re 1 V/μPa.

Near field measurements were made to characterize the directionality of the noise footprint during various operational scenarios, but these measurements are not comparable to the far field measurements collected for this study. However, source levels derived from near field measurements for the *Synergy* on DP with and without coring averaged 146.6 and 150.9 dB re 1 μPa, respectively.[3] The relative difference in levels agrees with measurements collected for this study, that is, sound levels were slightly lower during coring.

RPS and Seiche collected far field measurements by towing the array with hydrophones positioned 92 and 292 m (101 and 319 yd) astern. The hydrophones were towed at 29.7 m (32.5 yd) depth. For the *Synergy* transiting at 5 kts, the average SPL was 125 and 117 dB re 1 μ Pa at 92 and 292 m (101 and 319 yd), respectively. For comparison, SPLs for this study were around 140 and 127 dB re 1 μPa at the same respective ranges (Fig. 3.84).The difference in levels can likely be attributed to differences in the apparatus and measurement environment. The 75-Hz low frequency limit of the hydrophones excludes a significant amount of the *Synergy*'s transit and DP noise. With most generators, engines, and thrusters operating at 1800 rpm, a large part of the vessel's noise occurred at 30 Hz (see 1/3-octave band level plot, Fig. 87). This energy is not included in the RPS and Seiche measurements. The South China Sea location was also deeper, which may have allowed more spreading loss to occur.

Uncertainty in Measurement Range for Synergy DP Tests

The source-receiver slant ranges for the three recorders were calculated using the coring well coordinates as a reference point, which corresponds to a central location aboard the *Synergy*. To estimate an uncertainty in the range measurement, it is assumed that the side thrusters are located amidships, and the azimuthal (bow) thruster is located approximately ¾ of the way to the bow from the central point. In this scenario, the recorder-side thruster range could be in error by up to 10 m (11 yd; half the vessel's beam) and the recorder-bow thruster range could differ by up to 39 m (43 yd; calculated from an overall length of 104 m [114 yd]). The main props could be as many as 50 m (55 yd) away from the central reference point.

At the closest measured drillsite-receiver range, the orientation of the *Synergy* to the line of recorders could result in an actual source-receiver range that is quite different, and the received levels could vary by as much as 5-6 dB. OBH B, at 1 km (0.6 mi) range, was largely unaffected.

In the case that the *Synergy*'s orientation changed between the DP-only and DP with coring tests, this disparity could account for the 5 dB difference between received broadband levels (Fig. 78 and Fig. 81). However, since the RPS and Seiche measurements showed the same trend (lower received level during coring) it is possible that the thrusters operate differently during coring – perhaps with less power. It should also be

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[3] Received levels were back propagated based on measured transmission loss in a single 1/3-octave band centered at 1 kHz. Significant uncertainty in the source levels is introduced by this back-propagation method, as well as from hull shielding and the limited accuracy of source-receiver distance measurements. The absolute values should therefore not be considered accurate; however, more confidence can be placed on the relative difference between levels for the two operating scenarios.

noted that due to changing direction and intermittent use of the thrusters in both tests, the received levels varied by 5-10 dB at each measured range.

Summary and Conclusions

An underwater acoustic study was carried out for Statoil's 2011Alaskan Chukchi Sea survey program. Measurements from this study were used to verify marine mammal safety radii around the *Duke's* 40 in^3 airgun array and 10 in^3 mitigation airgun, and to characterize sounds from vessels and sonar used in the Shallow Hazards and Geotechnical Soil Investigation programs. The *Duke's* 40 in^3 airgun array did not exceed the estimated pre-season 190, 180, 160, and 120 dB re 1 µPa safety radii. However, the corresponding measured safety radii for the 10 in^3 mini-airgun were greater than the pre-season estimates. The 90th percentile sound level threshold distances for the airgun systems are summarized in Table 3.28.

Marine mammal safety radii were also computed based on the proposed Southall et al. (2007) species specific auditory injury criteria. Unlike the NMFS criteria which were based on SPL levels, the Southall auditory injury criteria consider exposure to high peak levels (peak SPL) as well as cumulative exposure due to multiple pulses (cumulative SEL). The Southall criteria also apply M-frequency weighting to account for differences in frequency-dependence of hearing sensitivity between four different marine mammal functional hearing groups. M-weighted cumulative SEL were calculated for reference only, and were not applied for determining operational safety radii for the Statoil Shallow Hazards survey. Distances from the airgun array at which the Southall auditory injury criteria would be reached were computed from cumulative M-weighted SEL and peak SPL measurements. The auditory injury distances according to these criteria were less than the distances based on the 190 and 180 dB re 1 µPa *rms* SPL criteria.

Source spectra, 1/3-octave band levels, and broadband source and received levels for all active sonar were characterized in this study. Sound level threshold distances for all sonar were computed and the 90th percentile distances maximized over direction are summarized in Tables 29 and 30.

Sound level threshold distances were calculated for several scenarios of vessel noise from the *Duke* and *Synergy*. The threshold distances and source levels are summarized in Tables 31.

TABLE 3.28. 40 in^3 airgun array and 10 in^3 mini-airgun 90th percentile threshold radii at the *Duke's* measurement site (from Tables 7 and 10). Distances are in meters.

SPL_{rms90} Threshold (dB re 1 µPa)	40 in^3 airgun array	10 in^3 mini-airgun
190	37	15*
180	130	59
170	460	230
160	1500	840
150	4300	2800
140	10000	7800
130	19000	17000
120	30000*	29000*

*Extrapolated beyond measured range (see Tables 7 and 10 for range values).

TABLE 3.29. *Duke's* sonar 90th percentile threshold radii (from Tables 13-18). Distances are in meters.

SPL_{rms90} Threshold (dB re 1 μPa)	Simrad EA502 single-beam sonar	Kongsberg SBP300 Sub-bottom profiler	GeoAcoustics 159D Side-scan sonar	Kongsberg EM2040 Multibeam sonar	SonarDyne Ranger Pro USBL	SonarDyne Ranger Pro USBL beacon
190	-	-	22	-	7*	-
180	-	-	47	-	13*	-
170	38**	-	100	-	25*	-
160	40**	30**	230	-	47	26
150	104	30**	490*	27	88	69
140	220	34	1100*	62	160	170
130	470	130	2400*	140*	280	380
120	1000	450	5100*	330*	470	750***
110	2100*	1400				

*Extrapolated beyond measurement range (see Tables 13-18 for range values).

**Actual maximum slant range that the threshold was exceeded. Not from fit function.

***This radius is from the in-beam measurements even though the out-of-beam radius is larger. As noted in Table 3.18, the extrapolated out-of-beam radius is likely overestimated due to the large offset required for the 90% fit. The measured in-beam radius is therefore considered to be more accurate.

TABLE 3.30. *Synergy's* sonar 90th percentile threshold radii (from Tables 20-22). Distances are in meters.

SPL_{rms90} Threshold (dB re 1 μPa)	Kongsberg EA600 single-beam sonar (18 kHz)	Kongsberg EA600 single-beam sonar (200 kHz)	Kongsberg HiPAP 500 (22/23 kHz)	Kongsberg HiPAP 500 (21/21.5 kHz)
190	6*	12*	4*	-
180	11*	16*	9*	1*
170	19*	21*	20*	3*
160	34*	27*	44*	7*
150	60	35*	96	20*
140	110	45	210	52*
130	190	58	460	140
120	340	75	1000	370

*Extrapolated beyond measurement range (see Tables 20-22 for range values).

TABLE 3.31. Vessel noise 90th percentile threshold radii (from Tables 19 and 23-25). Distances are in meters.

SPL_{rms} Threshold (dB re 1 μPa)	*Duke* transiting at 4.5 kts	*Synergy* in DP without coring	*Synergy* in DP during coring	*Synergy* transiting at 4.5 kts
170	-	1*	-	-
160	11*	6*	2*	1*
150	50	25*	9*	6*
140	220	110	53*	37
130	960	510	300	250
120	4200*	2300*	1800*	1600

*Extrapolated beyond measurement range (see Tables 19 and 23-25 for range values).

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

This chapter describes the marine mammal monitoring and mitigation measures implemented during Statoil's site survey and geotechnical coring operations in the Chukchi Sea during the 2011 open-water season. The required measures were detailed in the IHA and LOA issued to Statoil by the National Marine Fisheries Service (NMFS) and the U.S. Fish and Wildlife Service (USFWS), respectively. It 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 marine mammal monitoring program were to ensure that the provisions of the IHA and LOA issued to Statoil were satisfied, effects on marine mammals were minimized, and residual effects on animals were documented. Tasks specific to monitoring are listed below:

- use of dedicated Marine Mammal Observers (MMOs) aboard the seismic source vessel, to visually monitor the occurrence and behavior of marine mammals near the airguns when the airguns were operating and during a sample of the times when they were not;
- use the visual monitoring data as a basis for implementing the required mitigation measures;
- record (insofar as possible) the effects of the airgun operations and the resulting sounds on marine mammals;
- 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 and other industrial sound sources are customarily defined as the distances within which received 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 USFWS for the species under its jurisdiction (≥180 dB [rms] for walrus and ≥190 dB [rms] for polar bear, respectively) in the LOA issued to Statoil. These safety criteria are based on a cautionary assumption that sound energy at lower received levels will not harm these animals or impair their hearing abilities, but that higher received levels might have some such effects. Statoil's 2011 authorizations also required implementation of mitigation measures for large groups (≥12 individuals) of bowhead or gray whales (IHA) and Pacific walruses (LOA) that occurred within an area where sound levels were ≥160 dB (rms). Marine mammals exposed to pulsed sounds ≥160 dB (rms) or continuous sounds ≥120 dB (rms) are assumed by NMFS to be potentially subject to behavioral disturbance.

Statoil's IHA and LOA applications described the anticipated underwater sound field around the planned airgun cluster (4×10 in^3 airguns) towed at a depth of 2 m (7 ft) based on the 2009 sound source verification (SSV) measurements on the Burger prospect of a similar array, towed at a similar depth (Reiser et al. 2010). Field measurements of the received airgun sounds as a function of distance and

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[1] By Kris Hartin, Lauren Bisson, Sarah Case (LGL Alaska Research Associates, Inc.)

aspect were acquired during the beginning of seismic data acquisition (Warner et al. 2011) and are reported in Chapter 3 of this report. During the 2011 field measurements and until those results were available, the modeled safety radii distances were used for mitigation purposes. The 2011 measured sound propagation distances (radii) were similar to the modeled radii, although the measured radii from the 40-in^3 cluster were somewhat less than the modeled radii, while the measured radii from the single 10-in3 airgun were slightly greater than the modeled radii (Table 4.1). The preliminary empirical measurements of the ≥180 and ≥190 dB (rms) radii, as presented by Warner et al. (2011), were used by MMOs aboard the *Duke* as safety radii for the duration of Statoil's site survey. More extensive analysis of the field measurements was completed after the field season as described in Chapter 3 of this report.

Statoil's IHA and LOA applications described the predicted ensonified areas from the *Synergy* due to sounds produced by the dynamic positioning system and coring activities based on previous measurements of a vessel in dynamic positioning mode in the Chukchi Sea in 2010 (Chorney et al. 2011). Field measurements of the sounds produced by the *Synergy* while coring and in dynamic positioning mode were acquired at the beginning of geotechnical coring operations. While "shut-down" type mitigation measures were not always possible during coring activities and were unnecessary based on the measurements, MMOs aboard the *Synergy* continued to monitor the ≥120 and ≥160 dB (rms) zones after the measurement results were available. Preliminary and final radii for coring and dynamic positioning operations were less than the modeled ≥120 dB (rms) radii (Table 4.2).

TABLE 4.1. Comparison of measurements of the ≥190, 180, 160 and 120 dB (rms) distances (in km) for sound pulses from the 4-airgun, 40 in^3 array and 10 in^3 mitigation airgun deployed from *Duke* in the Chukchi Sea, Alaska, 2011.

	Full Airgun Array			**Mitigation Airgun**		
Received Level dB (rms)	**Modeled Radii**	**Preliminary Radii**	**Final Radii**	**Modeled Radii**	**Preliminary Radii**	**Final Radii**
≥190	0.050	0.037	0.037	0.010	0.015	0.015
≥180	0.190	0.130	0.130	0.045	0.059	0.059
≥160	2.250	1.500	1.500	0.715	0.840	0.840
≥120	39.000	30.000	30.000	24.000	29.000	29.000

TABLE 4.2. Comparison of measurements of the ≥160 and 120 dB (rms) distances (in km) for sound pulses from the coring and dynamic positioning operations from *Synergy* in the Chukchi Sea, Alaska, 2011.

	Coring and Dynamic Positioning			**Dynamic Positioning**		
Received Level dB (rms)	**Modeled Radii**	**Preliminary Radii**	**Final Radii**	**Modeled Radii**	**Preliminary Radii**	**Final Radii**
≥160	--	0.002	0.002	--	0.006	0.006
≥120	7.500	1.800	1.800	--	2.300	2.300

Mitigation Measures as Implemented

Through pre-season meetings with coastal communities and stakeholders, the location and timing of survey activities, especially in relation to subsistence uses of marine mammals, were considered when developing the mitigation plan for Statoil's site survey operations. During survey operations, the primary mitigation measures that were implemented included ramp up, delayed ramp up, power down, and shut down of the airguns. These measures are standard procedures during seismic surveys and are described in detail in Appendix C. Mitigation also included those measures specifically identified in the IHA and LOA as described below.

Standard Mitigation Measures

Standard mitigation measures implemented during the study included the following:

- Modeled safety radii (distances used in the IHA and LOA applications) were initially implemented during the seismic activities, and were revised to the preliminary results of the 2011 field measurements once they became available (Warner et al. 2011; Chapter 3; Table 4.1).
- In order for seismic operations to begin, the entirety of the ≥180 dB (rms) safety radius, the largest safety radii to be monitored by MMOs on the vessel, must have been visible for at least 30 minutes.
- 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.
- Power down or shut down procedures were implemented when a marine mammal was sighted within or approaching the applicable safety radius while the airguns were operating.
- A change in vessel course and/or speed alteration was identified as a potential mitigation measure 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. In practice, this measure was not implemented because the *Duke* was unable to maneuver quickly while towing the airguns and streamers.

The specific procedures applied during ramp ups, power downs, and shut downs are described in Appendix C. Briefly, a ramp up involved a gradual increase in the number of airguns operating (from no airguns or one airgun firing) usually accomplished by an addition of airguns such that the number of airguns operating is doubled approximately every 5 min. For the *Duke*, the ramp up duration was between 10 and 15 min. A power down involved reducing the number of operating airguns from the full array (40 in^3) to a single "mitigation" airgun (10 in^3) when a marine mammal was observed approaching or was first detected already within the full array safety radius. Power downs also occurred when the survey vessel was between seismic survey lines to reduce the amount of sound energy introduced into the water. A shut down involved suspending operation of all airguns. A shut down was implemented if a marine mammal was sighted within or approaching the safety radius of the mitigation airgun either after the full array had been powered down or upon initial observation.

Special Mitigation Measures as Required by NMFS and USFWS

In addition to the standard safety radii based on the ≥190 and ≥180 dB (rms) distances for pinnipeds and cetaceans, NMFS and USFWS required Statoil to monitor the ≥160 dB (rms) radius for aggregations of 12 or more non-migratory bowhead or gray whales and Pacific walruses during all seismic activities. Due to the relatively small size of the ≥160 dB (rms) zone, observers aboard the source vessel could monitor this area without the need for observers on additional vessels. Power down or shut down procedures were to be implemented if groups of 12 or more bowhead whales, gray whales, or Pacific walruses were observed within the ≥160 dB (rms) radius while the airguns were in operation.

Marine Mammal Monitoring Methods

Marine mammal monitoring methods were designed to meet the requirements specified in the IHA and LOA as listed above. The main purposes of MMOs aboard the seismic source vessel were as follows:

- Conduct monitoring and implement mitigation measures to avoid or minimize exposure of cetaceans and walruses to airgun sounds with received levels ≥180 dB (rms), or of other pinnipeds and polar bears to ≥190 dB (rms).
- Conduct monitoring and implement mitigation measures to avoid or minimize exposure of groups of 12 or more bowhead or gray whales and/or Pacific walruses to airgun sounds with received levels ≥160 dB (rms).
- 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 marine mammal monitoring are presented in Chapters 5 and 6.

The visual monitoring methods that were implemented during Statoil's 2011 survey operations were similar to those used during similar previous operations conducted under IHAs since 2003. The standard visual observation methods are described below and in Appendix C.

During the site survey, at least one MMO onboard the seismic source vessel *Duke* maintained a visual watch for marine mammals 24 h per day 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, Fujinon 25×150 "Big-Eye" binoculars or U.S. Nightvision class 3 night vision goggles. MMOs instructed seismic operators to power down or shut down the airguns if marine mammals were sighted within or about to enter applicable safety radii.

Changes to Monitoring Program Made based on Peer Review Panel Recommendations

As part of the NMFS IHA application processes, an independent peer review panel reviewed and provided comments and recommendations on the proposed marine mammal mitigation and monitoring plan. Recommendations were made for training procedures, field observation techniques, data recording procedures, and final reporting. A number of the recommendations made by the panel have been a part of similar monitoring programs in past years and were therefore already a part of the planned program in 2011 including:

- training of all observers, including Alaska Natives, together at the same time,
- observers were trained using visual aids (e.g., photos) to help them identify the species that they were likely to encounter in the conditions under which the animals would likely be seen,
- new and experienced observers were paired together during training and in the field to maximize understanding and consistency of data collection,
- observers documented visibility conditions during observation periods,
- observers maximized time spent monitoring areas within the safety radii rather than evaluating behavior,

- observers were situated in the best possible positions for observing: the bridge and the bridge wings,
- "Big eye" binoculars, low power binoculars, and naked eye searches were alternated during watches to cover the greatest area allowable by weather conditions,
- Observers recorded pertinent biological information for any "unknown" or "unidentified" marine mammal sighted,
- Time, location, and environmental conditions were recorded whenever survey activities changed, including mitigation gun firing, ramp up periods, seismic testing, and full array firing, or every 30 min if no change in activity had occurred.

Several of the recommendations made resulted in changes to the 2011 monitoring program, including:

- observers tested and analyzed night vision efficacy,
- An electronic database was used to record environmental information and sighting in real time, and allowed near real-time geographic display of the data.

According to recommendations on reporting procedures, this report has expanded to include:

- grouping of all seismic activity to compare between two categories "seismic" and "non-seismic,"
- estimates of statistical power in reported results from hypothesis tests.
- the addition of all sightability curves for distance based analyses,
- several graphical and statistical suggestions to better represent estimates of take, and
- comparisons between estimated and authorized takes.

Data Analysis Methods

Categorization of Data

Observer effort and marine mammal sightings were divided into several analysis categories related to environmental conditions and vessel activity. The categories were similar to those used during various other recent seismic studies conducted under IHAs in this region (e.g., 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 C.

Species Groups

Results are presented separately by species groups including cetaceans, pinnipeds (excluding walrus), Pacific walrus and polar bear. Cetaceans and pinnipeds are treated separately due to expected differences in potential reactions to industrial activities. Pacific walrus are presented separately due to their management by USFWS. No polar bears were observed during this project.

Geographic Boundaries and Vessel Role

Data were collected during the entire cruise period for both vessels including the transit between Dutch Harbor and the survey area, and the transit between Wainwright and the survey area. For the purposes of this report, only data recorded north of Point Hope were summarized in Chapters 5, 6 and 7.

Data were categorized by the duties of the vessel on which the data were collected. All data collected by MMOs aboard the site survey vessel, *Duke*, were categorized as "seismic vessel" data and are presented in Chapter 5. All data collected by MMOs aboard the *Synergy* were categorized as "coring vessel" data, and these data are further broken down into periods when the vessel was moving or stationary. All coring vessel data are presented in Chapter 6.

Vessel or Survey Activity

Sighting and observer effort data from the *Duke* were categorized into two groups depending on airgun status. Periods of seismic testing, ramp up, mitigation gun activity, and full array activity were grouped as "seismic". Periods with no airgun activity were categorized as "non-seismic".

Sighting and observer effort data from the Synergy were categorized into three bins. These included moving periods (mostly transit to and from the study site and between boreholes), stationary periods without coring activities, and stationary periods when coring was occurring.

Sighting Rate Calculation and Comparisons

Sighting rates (sightings/1000 km of observer effort for *Duke*, sightings/10 hr of observer effort for *Synergy*) are presented for both vessels within the analysis categories of Beaufort wind force (Bf), number of MMOs on watch, and by seismic status (for the *Duke*) or coring status (for the *Synergy*). Sighting rates are presented independently by species groups including cetaceans, pinnipeds (excluding walrus), and Pacific walrus. Where appropriate and sample sizes permitted, comparisons of sightings rates between categories were made using a Wilcoxon (Mann-Whitney U) signed-rank test or a chi-square (χ^2) test and results of a post-hoc power analysis have also been included. The power analysis of the Wilcoxon tests were baesd on a t -test power analysis, with sample sizes corrected for the asymptotic relative efficiency of the Wilcoxon test relative to the t-test (Lehmann 1975). That is, the sample sizes were multiplied by 0.955 (and rounded to the nearest integer) before performing the t-test power analysis. The effect size (d) was calculated according to Cohen (1988), where $d = (\mu_1 - \mu_2)/\sigma$ [μ_1 = mean of group 1; μ_2 = mean of group 2; and σ = standard deviation calculated across all samples]. Power analysis of chi-square tests were completed using the G*Power software (Faul et al. 2007).

Sighting rates have the potential to be biased by a number of different factors other than the variable being considered. In order to present meaningful and comparable sighting rates within and between categories, 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 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.

Criteria for Sighting Rate Data

Different definitions were used for pinnipeds 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 sighting rates and densities:

- 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 aboard a vessel 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 that 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 D for Beaufort wind force definitions);
- >60º of severe glare in the forward 180° of the vessel.

This categorization system was designed primarily to allow identification of 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 and other industrial sounds, likely diminish with time after the cessation of the 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 C. Data that met these criteria are presented in Parts 2 and 3 of Appendix F.

Distribution and Behavior

Initial Sighting Distance and Distribution

For each sighting, MMOs recorded an initial sighting distance and a direction of animal movement. Polar plots created for each vessel display the distribution, direction, and initial sighting distance of marine mammals. Sightings were classified by seismic activity and coring activity as well sightings made during periods of good visibility and sightings made during periods of poor visibility.

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. The mean, standard deviation, and range of CPA distances to the observer or airgun array was calculated within the two seismic activity bins for data from the *Duke* or three vessel activity bins for data from the *Synergy*.

Similar to sighting rate calculations, the calculation of mean CPA distances and subsequent comparisons during different seismic or vessel activity 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 grouped into five categories: swim (move) away, swim (move) towards, neutral (e.g. parallel), none, or unknown. The observed movements of animals that fell into these categories were compared for each vessel across the two seismic activity bins or three vessel activity bins.

Initial Behavior

For each sighting, an initial behavior was recorded by the MMO. Animal behavior codes included: sink, thrash, fluking, diving, looking, logging, spyhop, swim, breach, lobtail, flipper slap, blow, bow riding, porpoising, rafting, wake riding, unknown, walking, dead, and other. Activities, or a collection of behaviors that indicate an overall behavioral state, were also included as an initial behavior if MMOs clearly observed animals exhibiting these combinations of behaviors. Activity codes included: traveling, surface active, surface active-travel, milling, feeding, mating, and resting. The initial behaviors recorded for each sighting were summarized and compared for each vessel and across the two seismic activity bins or three vessel activity bins.

Reaction Behavior

Animal reactions in response to the vessel, seismic sound source, or coring activities were recorded during each sighting. Reaction behavior codes included: change in direction, increase or decrease in speed, look, splash, rush, bowriding or wake riding, interactions with gear, and no reaction. The reaction behaviors of animals that fell into these categories were compared for each vessel and across the two seismic activity bins or three vessel activity bins.

Line Transect Estimation of Densities

Marine mammal sightings recorded during seismic and non-seismic periods were used to calculate separate densities (#/km^2) of marine mammals near the vessels during those periods. The number of sightings made from the *Synergy* while it was stationary at the survey site was quite limited; therefore, only sightings and effort from the two vessels while they were underway were used to calculate densities. Density calculations were based on line-transect principles (Buckland et al. 2001). Sample sizes available from the two project vessels in 2011 were insufficient to allow independent calculation of correction factors for animals not detected at greater distances from the vessels [i.e. detection functions, $f(0)$]. Therefore, sightings from 2011 were pooled with sightings in the Chukchi Sea from vessels of similar height from 2006–2010 to calculate the detection functions. These detection functions are provided in Appendix C. 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 data analysis are provided in Appendix C.

Estimating Numbers Potentially Affected

NMFS and USFWS practice in situations with intermittent impulsive sounds like seismic pulses has been to assume that “take by harassment” (Level B harassment) may occur if marine mammals are exposed to received sound levels exceeding 160 dB re 1 μPa rms (NMFS 2005, 2006; USFWS 2008). For continuous sounds, like those created by the coring activities, Level B harassment is assumed to occur at received levels ≥120 dB re 1 μPa rms. When calculating the number of mammals potentially affected as described below, we used the measured ≥160 dB (rms) distances from the seismic source shown in Table 4.1, and the measured ≥120 dB (rms) distance from the *Synergy* during coring activities shown in Table 4.2.

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

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

(B) estimates based on pinniped and cetacean densities calculated from data collected from the two vessels during good visibility conditions and non-seismic or non-coring periods multiplied by the area of water exposed to seismic sounds ≥160 dB (rms) or coring sounds ≥120 dB (rms) during all operations;

(C) estimates based on pinniped and cetacean densities calculated from data collected from the two vessels during good visibility conditions when seismic operations were ongoing multiplied by the area of water exposed to seismic sounds ≥160 dB (rms) or coring sounds ≥120 dB (rms) during all operations.

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 (C) provides an estimate of the number of animals that were likely present in the area of seismic activity during this project. In cases where seismic densities are 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 (e.g. increased their time spent at the surface). The actual number of individuals exposed to, and potentially affected by, seismic survey or coring 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 and Tasker 2006; Gordon et al. 2004; Smultea et al. 2004, Funk et al. 2008). Within the ≥160 dB (rms) radii around the seismic source (i.e., 1.5 km [0.9 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 and coring operations (methods B and C). In the case of airgun sounds from site survey activities, this involved multiplying the following three values:

- km of seismic survey;
- width of area assumed to be ensonified to ≥160 dB (rms) by pulsed airgun sounds (2 × ≥160 dB measured 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.

In the case of coring operations, the area ensonified by continuous sounds from the vessel's dynamic positioning system and coring equipment was calculated as the area of a circle with a radius equal to the measured ≥120 dB (rms) distance. The sum of the areas from the 18 coring locations, excluding any overlap of the ensonified areas, was then multiplied by the estimated marine mammal densities.

The ensonified area used in the above calculations did not include multiple counts of the same area of water that was exposed on multiple occasions. Areas within the survey area may have been ensonified by airgun sounds multiple times during the site surveys because survey transect lines were spaced closer together than twice the measured ≥160 dB distance (2 × 1.5 km = 3.0 km; see Appendix I for weekly maps of the survey activity. The acquisition of three to four geotechnical cores in close proximity to each other at the five potential well sites on Statoil's leases resulted in the overlap of areas ensonified to continuous sounds ≥120 dB (rms). 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 represents the average number of times a given area of water was ensonified to the specified level. If an animal remained at the survey site through the duration of the survey activities it would have been, on average, 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., Funk et al. 2008; Ireland et al. 2007a,b; Patterson et al. 2007).

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5. MARINE MAMMAL MONITORING RESULTS DURING SITE CLEARANCE SURVEYS[1]

Monitoring Effort and Marine Mammal Encounter Results

This chapter summarizes the visual observer effort from the *Duke* during Statoil's 2011 site surveys in the Chukchi Sea. It does not include effort conducted during transit from Dutch Harbor to and from the survey area (defined as waters north of Point Hope, Alaska). The *Duke* entered the Chukchi Sea survey area on 6 Aug 2011 Alaska Daylight Time (AKDT) and departed the area on 23 Sep 2011. Survey activities on the Statoil leases began with airgun testing on 7 Aug and continued through 20 Sep.

The *Duke* traveled along a total of ~9301 km (5779 mi) of trackline in the Chukchi Sea survey area. Airgun operations occurred along ~4962 km (3083 mi) of that trackline. The full airgun array was ramping up or active along ~3202 km (1990 mi) while the single mitigation airgun operated along ~1760 km (1094 mi), including turns and power downs. The airguns did not operate along the remaining~ 4339 km (2696 mi) of trackline in the Chukchi Sea.

Vessels other than those involved in Statoil's operations seldom passed through the project area. Each ship that was not participating in the project transited well away from survey activities (>15 km) and MMOs observed no instances of harassment or disturbance to marine mammals due to their presence.

Observer Effort

MMOs aboard the *Duke* were on watch for a total of ~8724 km (5421 mi; 1035 h), or 94% of all operations. At least one observer was on watch during 100% (~3842 km; 2387 mi; 463 h) of daylight seismic operations and two observers were on watch for ~88% (3397 km; 2111 mi; 409 h) of daylight seismic operations. At least one observer was on watch during 100% (~1120 km; 696 mi; 133 h) of nighttime seismic operations and two observers were on watch for ~55% (619 km; 385mi; 409 h) of nighttime seismic operations. Of the total observation effort, ~20% (1749 km; 1087 mi; 74 h) occurred during darkness (Fig. 5.1).

Observer Effort by Beaufort Wind Force

Observer effort from the *Duke* occurred between Beaufort wind force (Bf) zero and Bf eight (Fig. 5.2). The greatest amount of observer effort occurred during Bf three, which accounted for 31% of MMO effort aboard the *Duke.*

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[1] By Lauren Bisson, Kris Hartin, Sarah Case (LGL Alaska Research Associates, Inc.)

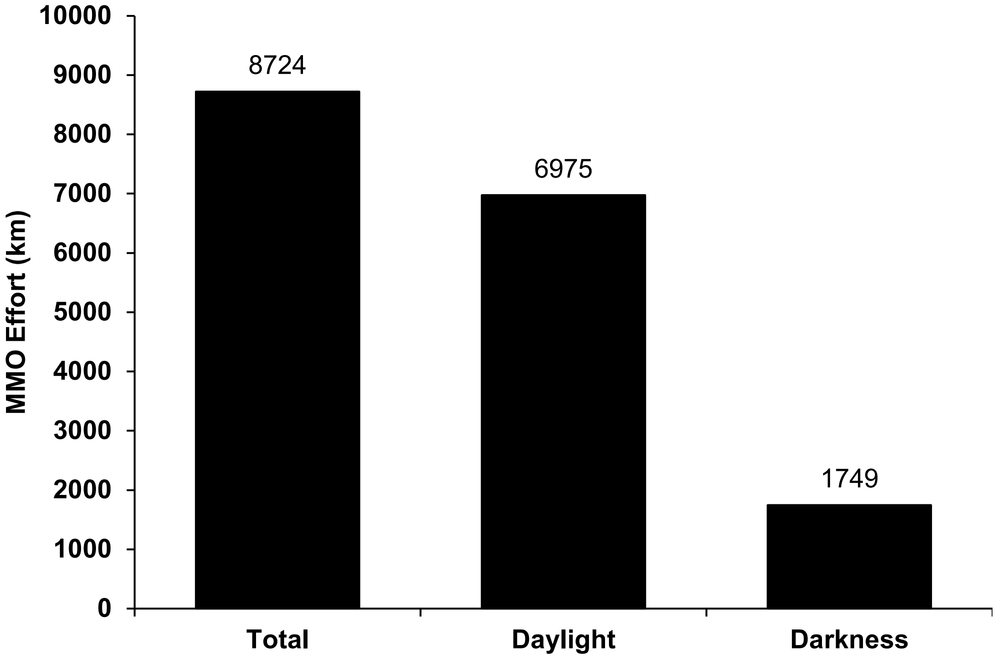

FIGURE 5.1. Total MMO observation effort (km), and MMO effort during daylight and darkness periods from the *Duke* during Statoil's site survey, 6 Aug – 23 Sep 2011.

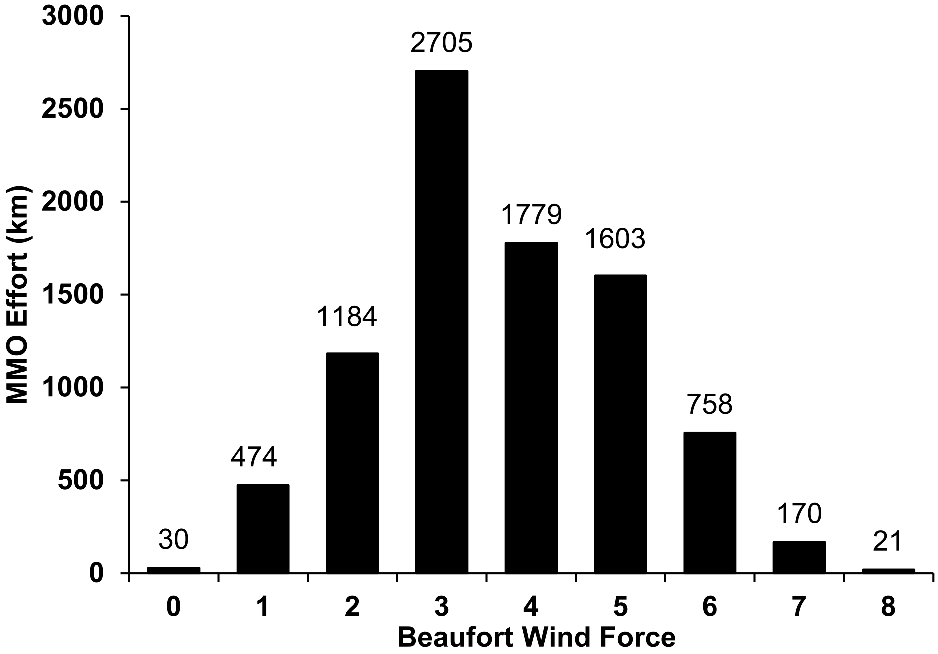

FIGURE 5.2. MMO observation effort (km) by Beaufort wind force from the *Duke* during Statoil's site survey, 6 Aug – 23 Sep 2011.

Observer Effort by Visibility

Recorded visibility distances tended to be quite large (≥8 km; ≥5 mi) or quite low (<1 km; <0.6 mi). This reflects the fact that watches occurred both during the day and at night, and periods of dawn and dusk were short in comparison (Figure 5.3). Periods of dense fog were relatively common during the day resulting in additional watch effort occurring during low visibility periods.

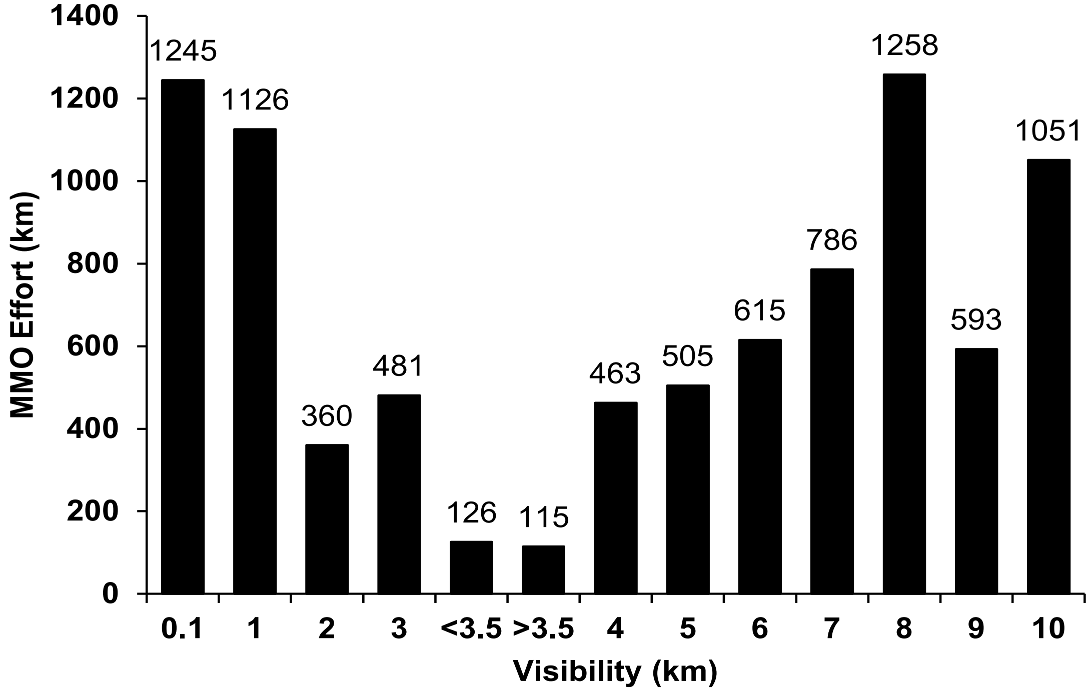

FIGURE 5.3. MMO observation effort (km) by recorded visibility distance (km) from the *Duke* during Statoil's site survey, 6 Aug – 23 Sep 2011. The <3.5 and >3.5 km categories were recorded by observers when visibility distance was highly variably (e.g. fast moving fog banks or low clouds) but tended to be above or below the 3.5 km distance.

Observer Effort by Number of MMOs

On the *Duke*, two MMOs were on watch during ~72% (6308 km; 3920 mi) of observation effort and one MMO was on watch for ~28% (2416 km; 1501 mi) of observation effort.

Observer Effort by Seismic Status

Most observer effort from the *Duke* occurred while the airguns were active; ~37% of total observer effort occurred while the full array was active and ~20% of total observer effort occurred while the mitigation airgun was active (Fig. 5.4). Observer effort during non-seismic periods accounted for the remaining ~43% of total effort.

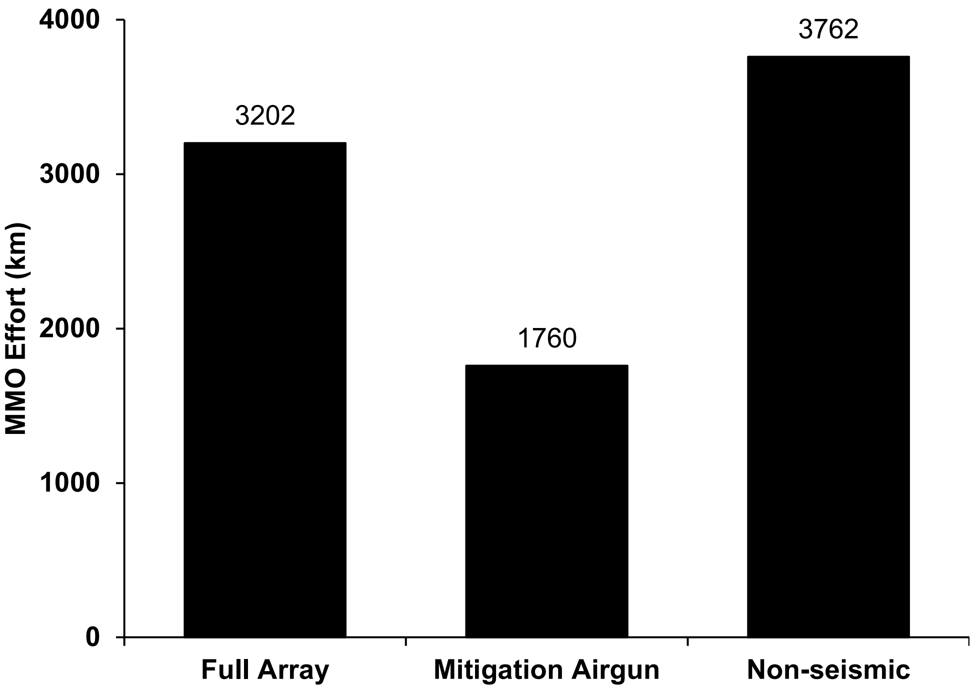

FIGURE 5.4. MMO observation effort (km) by seismic status from the *Duke* during Statoil's site survey, 6 Aug – 23 Sep 2011.

Marine Mammal Sightings

During the Statoil site survey, MMOs observed a total of 183 sightings of 246 marine mammals from the *Duke*. Details of each marine mammal sighting observed in the survey area are available in Appendix I. The sighting data below are presented in three species groups: cetaceans, seals, and Pacific walruses.

Cetacean Sightings

MMOs observed 11 sightings of 35 cetaceans from the *Duke* (Table 5.1), most of which were gray whales.

TABLE 5.1. Number of cetacean sightings (number of individuals) from the *Duke* during Statoil's site survey, 6 Aug – 23 Sep 2011.

Species	**Sightings (Individuals)**
Cetaceans	
Gray Whale	6 (29)
Unidentified Mysticete Whale	5 (6)
Total Cetaceans	***11 (35)***

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 C) and the sightings that occurred during those periods. Data that met these criteria are summarized and presented in Parts 2 and 3 of Appendix F.

Cetacean Sighting Rates by Beaufort Wind Force – Cetacean sighting rates were highest during Bf two (~72%; Fig. 5.5), although there was very little effort in Bf zero and a limited amount of effort in Bf one. Figure 5.7 shows the daily average Bf conditions along with the days on which cetacean sightings occurred. Sightings only occurred on three days, and the average Bf conditions on those days ranged from two to four. Gray whales are generally more common along the coast than in offshore areas and consistent with that, the highest number of cetacean sightings occurred on 28 Aug (during Bf 2), as the vessel transited to and from Wainwright.

Cetacean Sighting Rates by Visibility Distance – Cetacean sighting rates tended to increase with increased visibility, but there were no sightings with visibility lower than 6.5 km. The greatest sighting rate occurred when the visibility distance was recorded as nine km (Fig. 5.6). There was a similar amount of effort during periods with nine km visibility as there were during periods of four, five, and six km of visibility (Fig 5.3) indicating that these rates are not necessarily due to increased effort during periods of increased visibility. Alternatively, the high sighting rate during periods with visibility of nine km is likely due to the high number of sightings during the trip to Wainwright on 28 August, during which visibility was consistently recorded as nine or ten km.

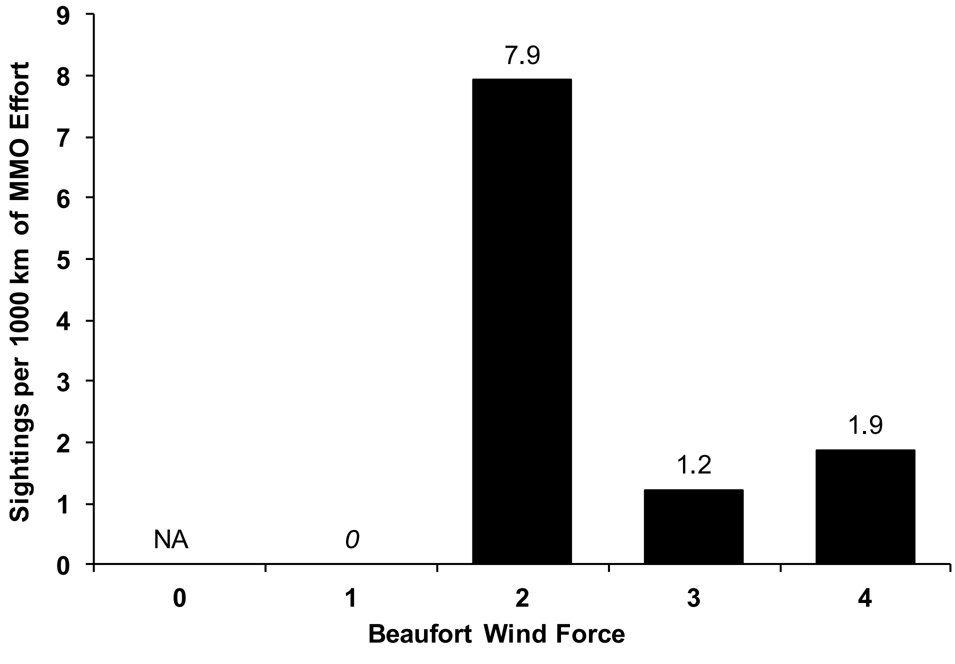

FIGURE 5.5. Cetacean sighting rates by Beaufort wind force conditions from the *Duke* during Statoil's site survey, 6 Aug – 23 Sep 2011. NA indicates that there was insufficient effort in the category to calculate a sighting rate. Italicized numbers indicate that the sighting rate may not be reliable due to a limited amount of observation effort having occurred within the category.

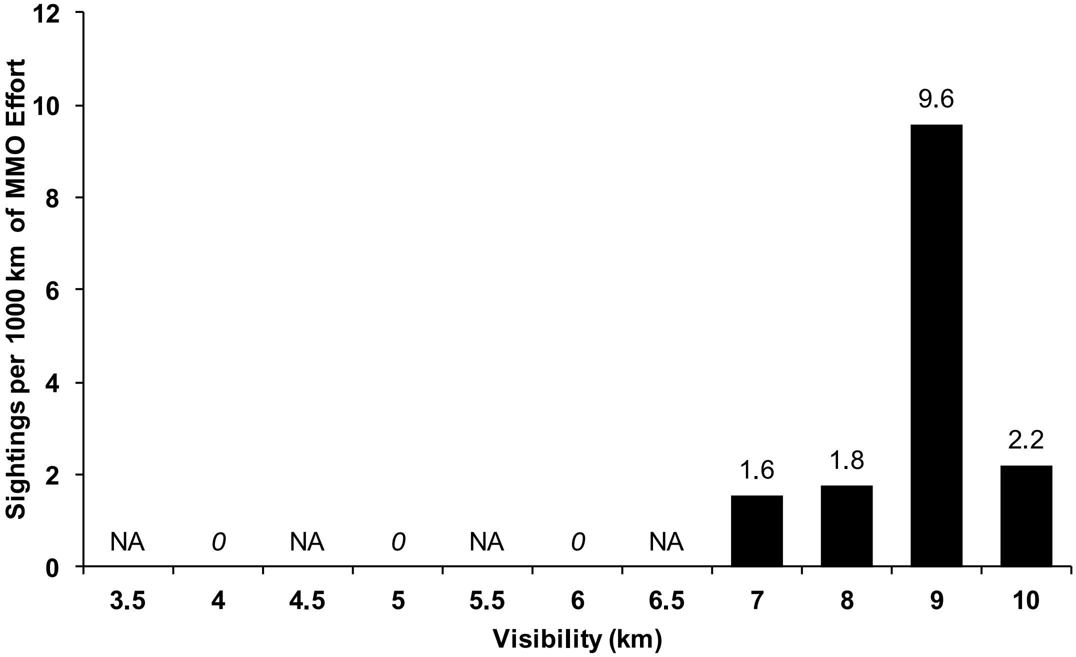

FIGURE 5.6. Cetacean sighting rates by visibility (km) from the *Duke* during Statoil's site survey, 6 Aug – 23 Sep 2011. NA indicates that there was insufficient effort in the category to calculate a sighting rate. Italicized numbers indicate that the sighting rate may not be reliable due to a limited amount of observation effort having occurred within the category.

Cetacean Sighting Rates by Number of MMOs – There were relatively few periods on the *Duke* during which one MMO was on watch and no periods where three MMOs were on watch. Cetaceans were only sighted with two MMOs on watch.

Cetacean Sighting Rates by Seismic Status – Only one of the eleven cetacean sightings occurred while airguns were active, and in that case only the single mitigation airgun was operating. The majority of cetacean sighting occurred during the trip to Wainwright on 28 August, when the vessel was off of the site survey area and therefore was not operating the airguns.

Seal Sightings

There were 109 seals sightings of 111 individuals by MMOs on the *Duke* (Table 5.2). Bearded seal was the most frequently identified seal species, although nearly a third of the seals sighted could not be identified to species.

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 C) and the sightings that occurred during those periods.

Seal Sighting Rates by Beaufort Wind Force – Seal sighting rates from the *Duke* were greatest during periods of Bf one and two (Fig. 5.7) and tended to decrease as Bf increased. Figure 5.8 shows the number of seal sightings each day along with the average daily wind force.

Seal Sighting Rates by Visibility Distance – Seal sighting rates tended to increase with an increase in visibility (Fig. 5.9).

TABLE 5.2. Number of seal sightings (number of individuals) from the *Duke* during Statoil's site survey, 6 Aug – 23 Sep 2011.

Species		**Sightings (Individuals)**
Seals		
Bearded Seal		59 (61)
Ringed Seal		18 (18)
Spotted Seal		1 (1)
Unidentified Pinniped		12 (12)
Unidentified Seal		19 (19)
	Total Seals	***109 (111)***

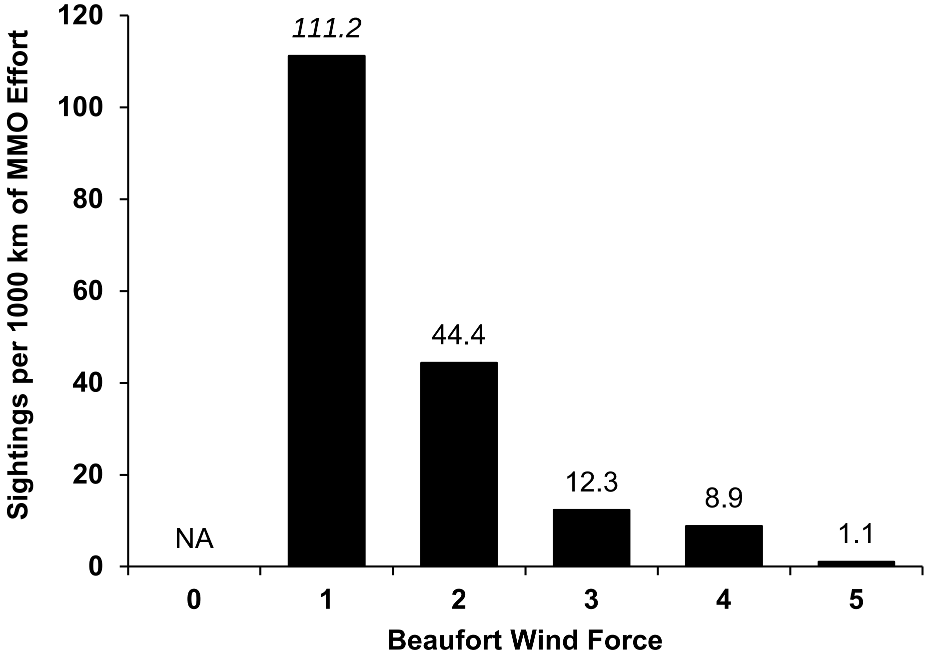

FIGURE 5.7. Seal sighting rates by Beaufort wind force level from the *Duke* during Statoil's site survey, 6 Aug – 23 Sep 2011. NA indicates that there was insufficient effort in the category to calculate a sighting rate. Italicized numbers indicate that the sighting rate may not be reliable due to a limited amount of observation effort having occurred within the category.

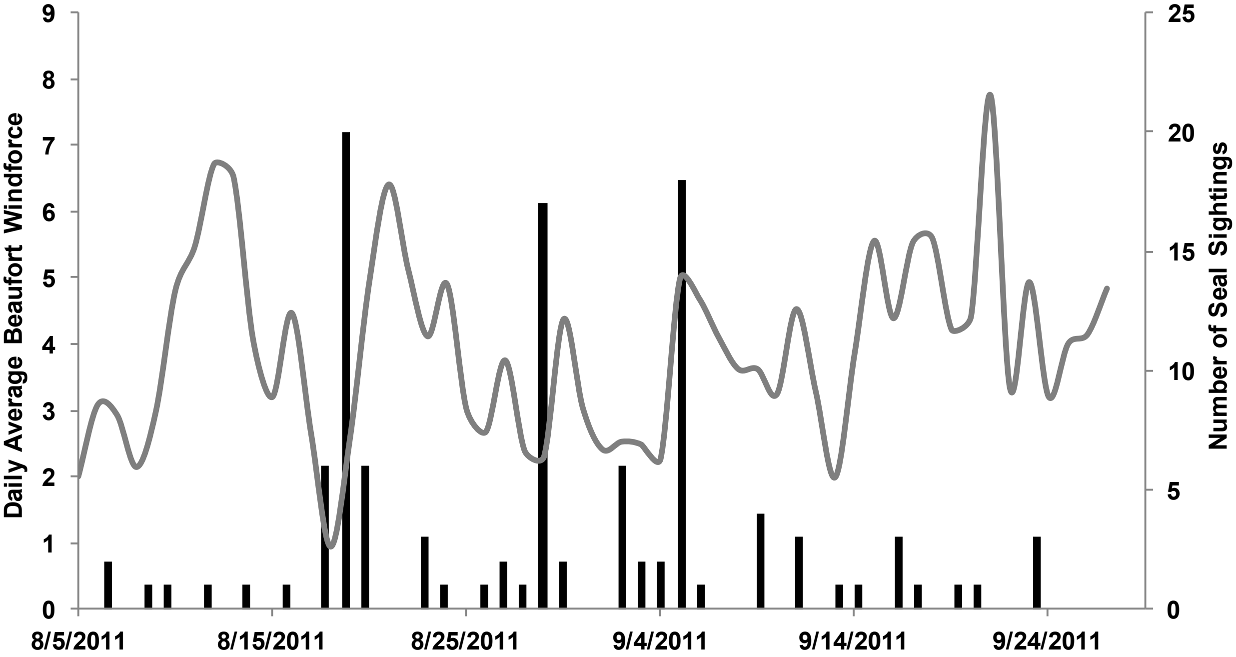

FIGURE 5.8. Seal sightings and daily average Beaufort wind force conditions from the *Duke* during Statoil's site survey, 6 Aug – 23 Sep 2011.

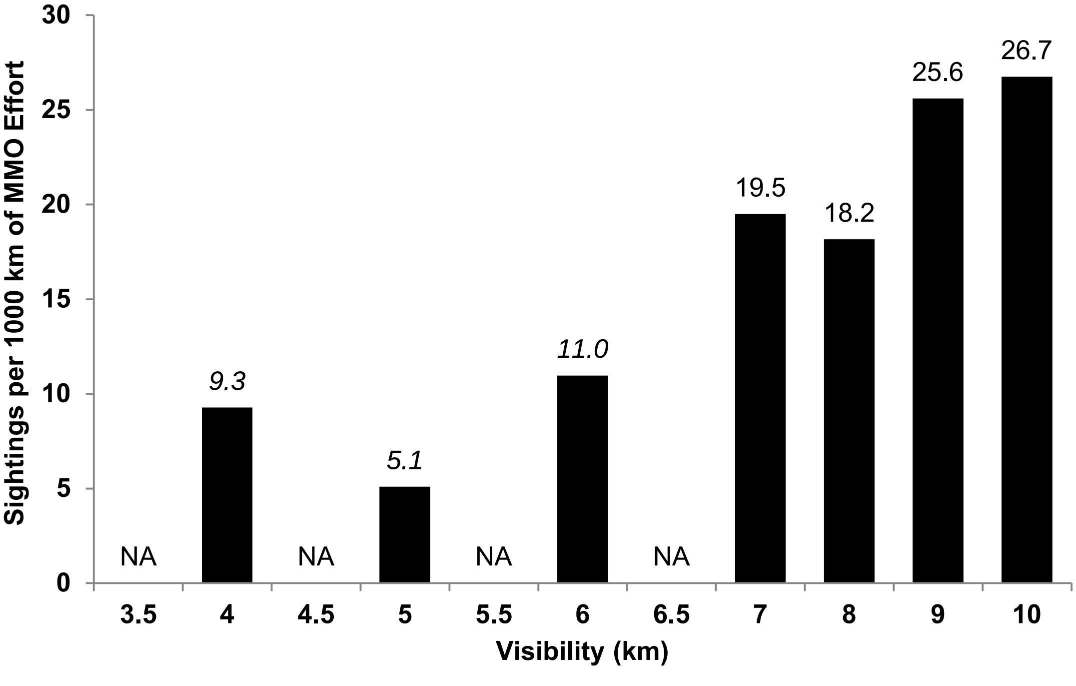

FIGURE 5.9. Seal sighting rates by visibility (km) from the *Duke* during Statoil's site survey, 6 Aug – 23 Sep 2011. NA indicates that there was insufficient effort in the category to calculate a sighting rate. Italicized numbers indicate that the sighting rate may not be reliable due to a limited amount of observation effort having occurred within the category.

Seal Sighting Rates by Number of MMOs – Seal sighting rates with two MMOs on watch (20.4 seals/1000 km) were nearly 4 times greater than with one MMO on watch (5.4 seals/1000 km) and the difference was statistically significant ($X^2 = 5.9$, $df = 1$, $p = 0.01$, power [1-β] = 0.15). However, limited effort (560 km; 348 mi) occurred when there was one MMO on watch, so that sighting rate should be viewed with some caution.

Seal Sighting Rates by Seismic Status – The seal sighting rate from the *Duke* was slightly higher when the airguns were active than when they were not (Fig. 5.10).

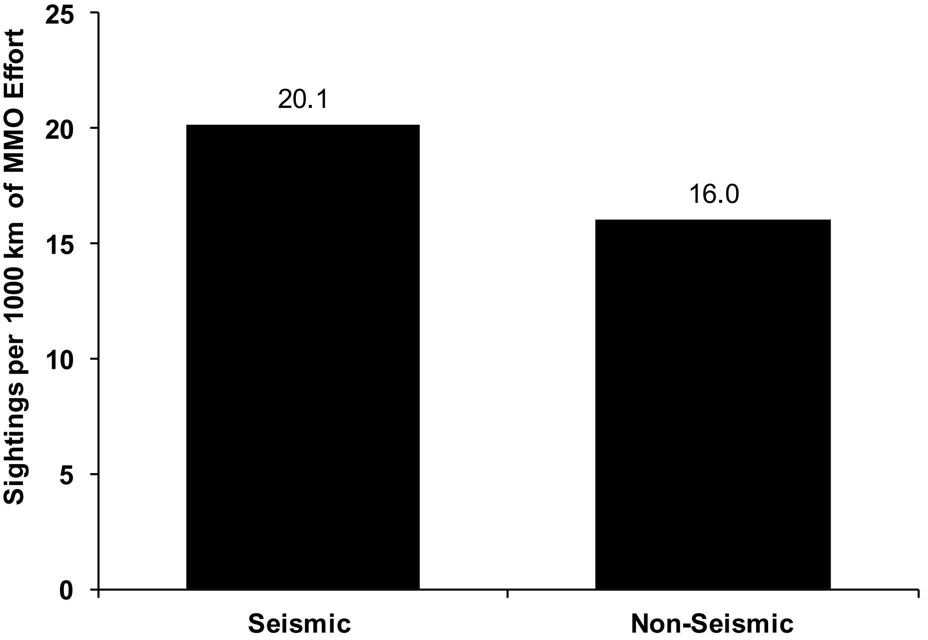

FIGURE 5.10. Seal sighting rates by seismic status from the *Duke* during Statoil's site survey, 6 Aug – 23 Sep 2011.

Polar Bear Sightings

No polar bears were observed during Statoil's site survey.

Pacific Walrus Sightings

There were 61 Pacific walrus sightings of 98 individuals by MMOs on the *Duke*. The majority of walrus sightings occurred on two separate days: 18 August (25 sightings) and 28 Aug (19 sightings). On 18 Aug the *Duke* was on the survey site and the high number of sightings was likely due to the movement of Pacific walruses toward haul outs on the Alaskan Chukchi Sea coast. Sightings made on 28 Aug occurred during the vessel transit to Wainwright and the proximity to land, and potential foraging areas of walrus using shore haul outs, likely resulted in the high number of Pacific walrus sightings.

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 walruses (See Chapter 4 and Appendix C) and the sightings that occurred during those periods.

Pacific Walrus Sightings by Beaufort Wind Force – The Pacific walrus sighting rate from the *Duke* was greatest during Bf one and sightings were generally less numerous with increased wind force (Figs. 5.11, 5.12).

Pacific Walrus Sighting Rates by Visibility Distance – There was no clear trend in Pacific walrus sighting rates when compared across visibility distances at the time of the sightings (Fig. 5.13), although sighting rates were certainly highest when visibility distances was greatest. Rates of Pacific walrus sightings (and coincident visibility conditions) were probably more influenced by specific time periods during which large numbers of walrus were moving towards haul outs along the Alaskan Chukchi Sea coast than visibility distance.

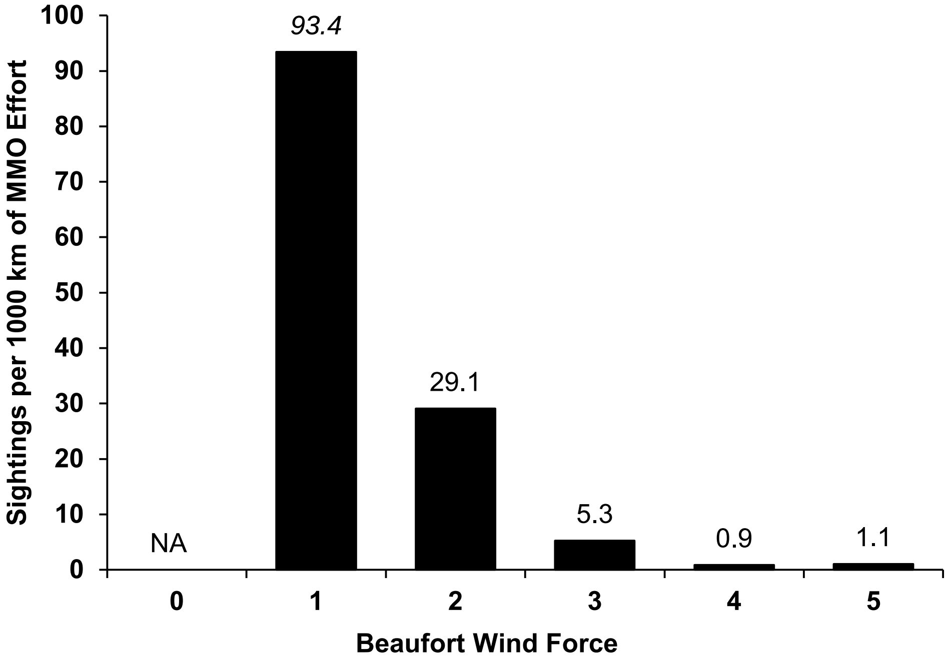

FIGURE 5.11. Pacific walrus sighting rates by Beaufort wind force level from the *Duke* during Statoil's site survey, 6 Aug – 23 Sep 2011. NA indicates that there was insufficient effort in the category to calculate a sighting rate. Italicized numbers indicate that the sighting rate may not be reliable due to a limited amount of observation effort having occurred within the category.

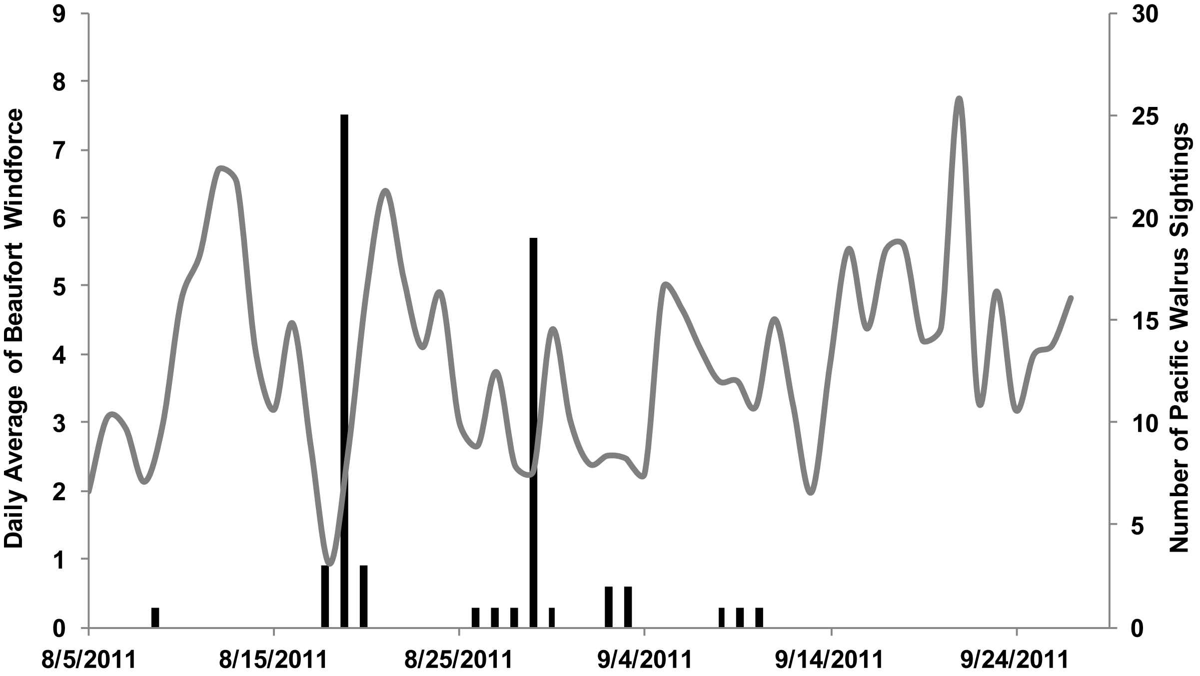

FIGURE 5.12. Pacific walrus sightings during daily average Beaufort wind force conditions from the *Duke* during Statoil's site survey, 6 Aug – 23 Sep 2011.

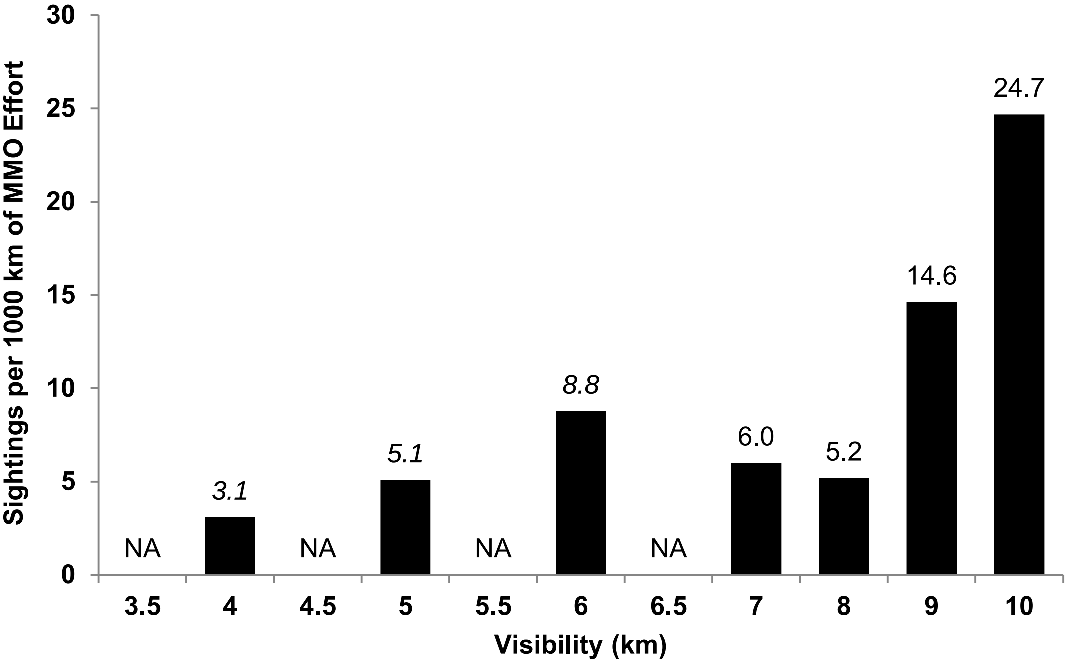

FIGURE 5.13. Pacific walrus sighting rates by visibility (km) from the *Duke* during Statoil's site survey, 6 Aug – 23 Sep 2011. NA indicates that there was insufficient effort in the category to calculate a sighting rate. Italicized numbers indicate that the sighting rate may not be reliable due to a limited amount of observation effort having occurred within the category.

Pacific Walrus Sighting Rates by Number of MMOs – Pacific walrus sighting rates with two MMOs on watch (12.3 walrus/1000 km) were over 6 times greater than with one MMO on watch (1.8 walrus/1000 km) and the difference was statistically significant ($X^2 = 4.9$, $df = 1$, $p = 0.03$, power [1-β] = 0.1) . However, limited effort (560 km; 348 mi) occurred when there was one MMO on watch, so that sighting rate should be viewed with some caution.

Pacific Walrus Sighting Rates by Seismic Status – The Pacific walrus sighting rate from the *Duke* was slightly higher when the airguns were active than when they were not active, but the difference was not statistically significant ($X^2 = 0.3$, $df = 1$, $p = 0.59$, power [1-β] = 0.05; Fig. 5.14). The difference in sighting rates may be more related to the timing of the walrus movement toward coastal haul outs than to airgun status as ~41% of walrus sightings occurred on 18 August, a day in which seismic activity was occurring.

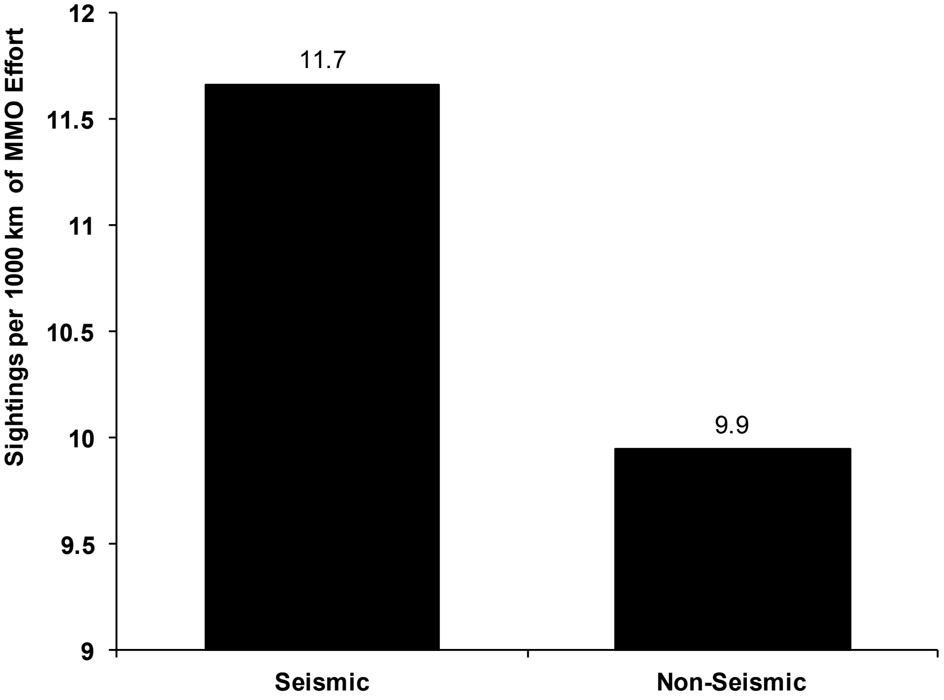

FIGURE 5.14. Walrus sighting rates by seismic status from the *Duke* during Statoil's site survey, 6 Aug – 23 Sep 2011.

Unidentified Marine Mammal Sightings

Of the 38 unidentified marine mammal sightings, two unidentified pinnipeds were carcasses in an advanced state of decomposition. The other 36 unidentified sightings were either too brief, too distant, or were during periods of poor visibility to accurately identify to species. Comments recorded by the observer at the time of each of these sightings (available in Appendix H) were used to assign a likely species in this section. Sightings with little or no diagnostic information in the comments field were left as unidentified sightings.

TABLE 5.3. Number of unidentified marine mammal sightings from the *Duke* during Statoil's site survey, 6 Aug – 23 Sep 2011.

Species	Sightings (Individuals)
Unidentified Marine Mammals	
Unidentified Mysticete Whale	5 (6)
Unidentified Pinniped	14 (14)
Unidentified Seal	19 (19)
Total Seals	***38 (39)***

Cetaceans – It is likely that 4 of the 5 unidentified whale sightings were gray whales due to the shape and size of their blow as well as physical whale descriptions listed at the time of sighting. Observer comments for one unidentified whale did not provide enough additional information to assign the sighting to a likely species.

Pinnipeds – Of the 33 unidentified pinnipeds and seals, 12 could be assigned a likely species using the descriptions recorded by the MMO at the time of the sighting. Details such as the size and color of the pinniped, the presence or absence of tusks, and the shape of the face led to the designation of seven bearded seals, four ringed seals, and one spotted seal. Twenty-one sightings of pinnipeds did not contain enough additional information in the comments field to assign a likely species.

TABLE 5.4. Number of reclassified sightings from unidentified pinniped and unidentified seal sightings from the *Duke* during Statoil's site survey, 6 Aug – 23 Sep 2011.

Species	Sightings (Individuals)
Pinnipeds	
Bearded Seal	7 (7)
Pacific Walrus	0 0
Ringed Seal	4 (4)
Spotted Seal	1 (1)
Unidentified Pinniped	7 (7)
Unidentified Seal	14 (14)
Total Seals	***33 (33)***

Distribution and Behavior of Marine Mammals

Cetaceans

Cetacean Initial Sighting Distance and Distribution

The initial sighting distance 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 C). All sightings of cetaceans that met these criteria were during non-seismic periods (Fig.5.15) and the mean initial sighting distance was 2088 m (2283 yd). Cetaceans were initially sighted from the *Duke* as close as 290 m (317 yd) and as far as 4208 m (4602 yd). At the time of the closest initial sighting, no mitigation requests were made as the vessel was already traveling slower than ten knots and the animal was observed moving away from the vessel.

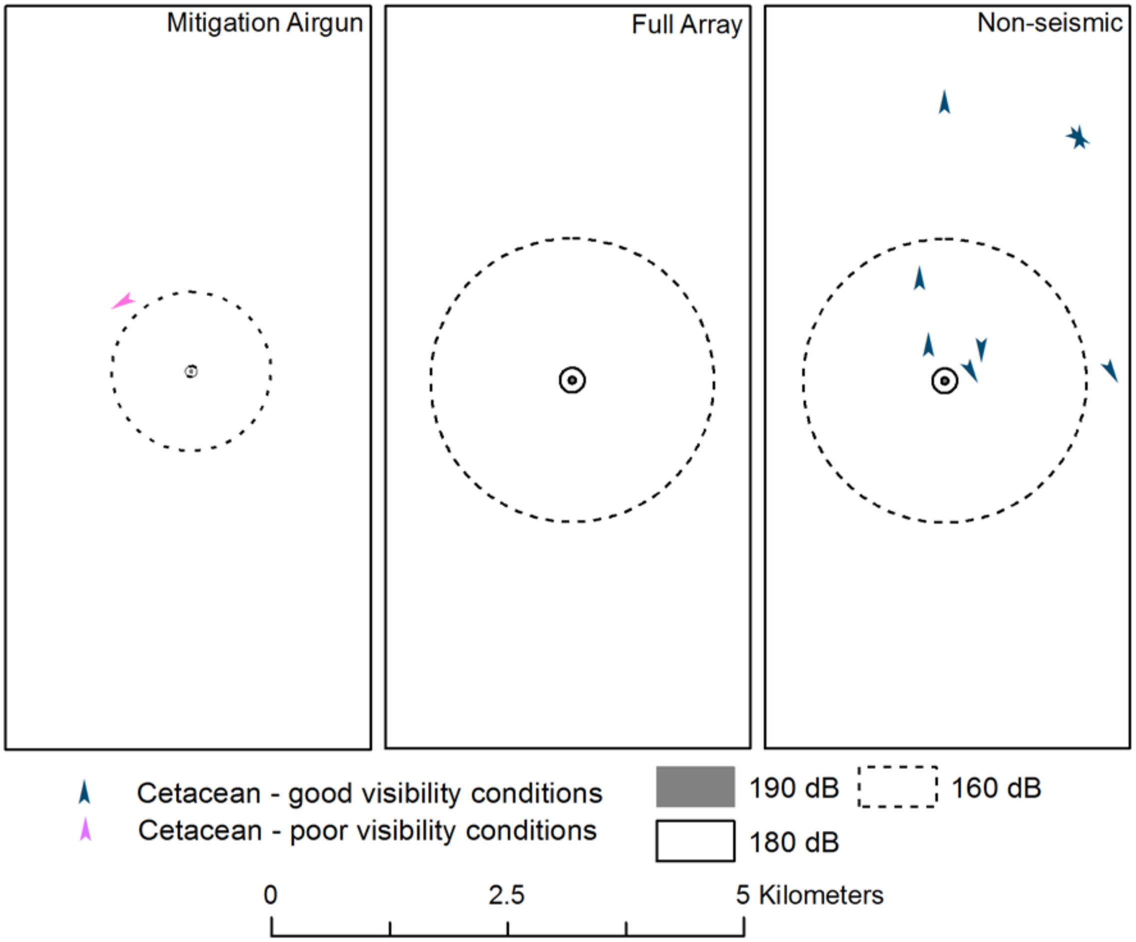

FIGURE 5.15. Initial cetacean sightings from the *Duke* by airgun status with safety and disturbance radii, during Statoil's site survey, 6 Aug – 23 Sep 2011. Arrows indicate direction of animal movement.

Cetacean Closest Point of Approach

The mean closest points of approach (CPAs) of cetaceans to the airguns were 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 C). The mean CPA during non-seismic periods was 1650 m (1805 yd). There were no cetaceans observed during seismic activities. Cetaceans were observed from the *Duke* as close as 229 m (250 yd) and as far as 4305 m (4708 yd). In order to standardize the data and allow meaningful comparisons, CPAs were calculated to the position of the airguns even when the actual airguns were not in the water or active. The cetacean observed 229 m (250 yd) away from the airgun position was a single animal in a larger group of cetaceans encountered during the transit to Wainwright when no airguns were in the water. In response to the multiple cetacean sightings, the vessel changed course and travelled well away from the group at a speed slower than ten knots. This single cetacean approached the vessel until it was ~200 m (219 yd) away from the observers before diving out of sight.

Cetacean Movement

The movement of all 11 cetaceans relative to the *Duke* was either unknown or neutral. Neutral movement included occasions when the animal(s) was swimming neither towards nor away from the vessel (e.g. parallel to vessel). Only one cetacean was sighted during seismic activity (mitigation airgun firing) and it was observed moving neutral relative to the vessel.

Cetacean Initial Behavior

The number of cetacean sightings was insufficient to make meaningful comparisons of differences in observed behaviors across periods with and without seismic activity. Most initial cetacean behaviors recorded from the *Duke* (10 of 11) were blow. This is typical because a blow is a highly visible sighting cue. The only other recorded behavior was dive (1 of 11).

Cetacean Reaction Behavior

No cetaceans sighted from the *Duke* exhibited an overt (or discernible) reaction to the vessel regardless of seismic activity.

Seals

Seal Initial Sighting Distance and Distribution

The mean initial sighting distance for seals observed from the *Duke* was significantly farther during seismic periods than during non-seismic periods ($W = 490.5$, $p = 0.002$, power $[1-\beta] = 0.78$; Table 5.5). This may suggest a short distance of "localized" avoidance of the airguns by seals. Seals were observed as close as 40 m (44 yd) and as far as 2863 m (3131 yd).

Seal Closest Point of Approach

The mean closest points of approach of seals to the airguns were 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 C). The mean CPA for seals observed from the *Duke* was significantly closer during non-seismic periods than during seismic periods ($W = 576.5$, $p = 0.02$, power $[1-\beta] = 0.48$; Table 5.6). Seals were observed as close as 123 m (134 yd) and as far as 2961 m (3238 yd).

TABLE 5.5. Comparison of mean seal initial sighting distances (m) by seismic status from the *Duke* during Statoil's site survey, 6 Aug – 23 Sep 2011. The overall mean includes initial sightings from seismic status bins.

Seismic Status	Mean Initial Sighting Distance (m)	s.d.	Range (m)	*n*
Seismic	451	476	50-2863	***57***
Non-Seismic	211	150	40-555	***29***
Overall	***370***	***412***	***40-2863***	***86***

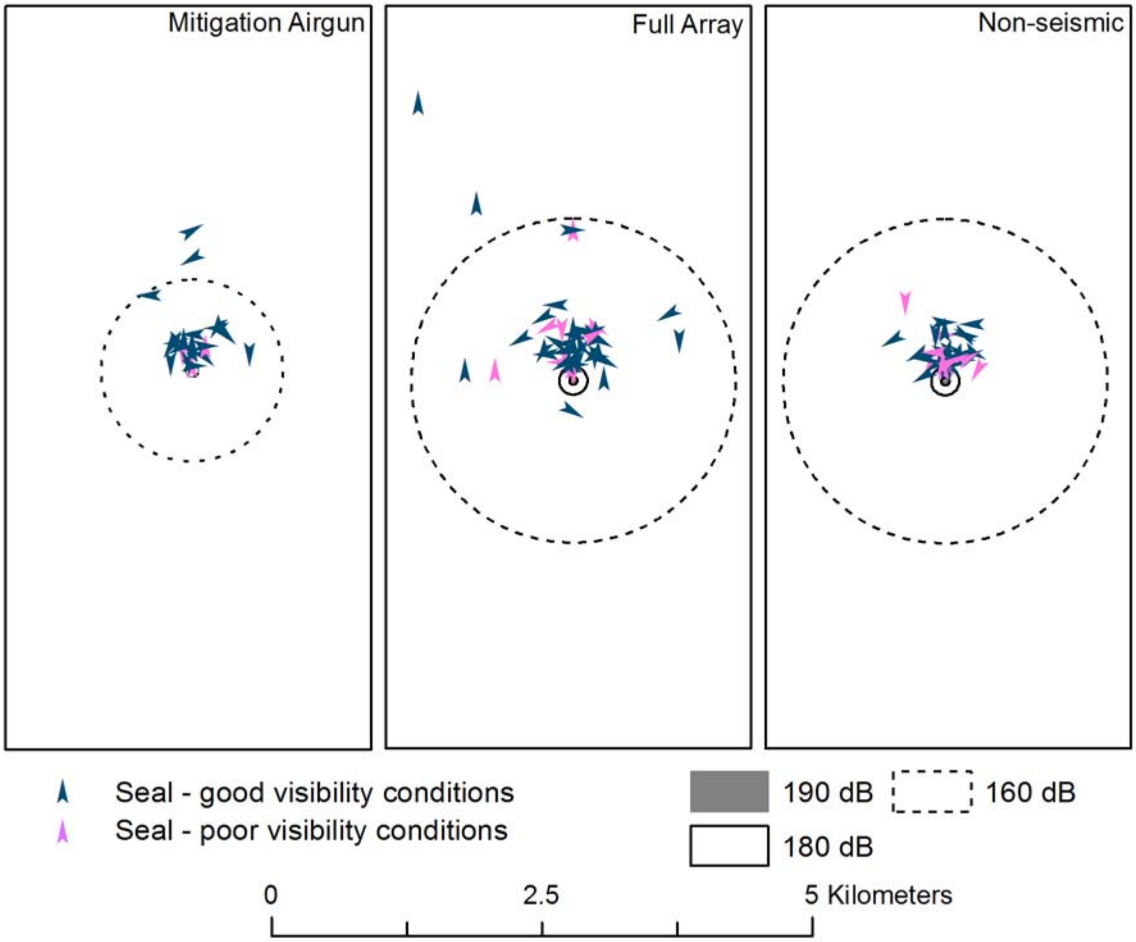

FIGURE 5.16. Initial seal sightings from the *Duke* by airgun status with safety radii, during Statoil's site survey, 6 Aug – 23 Sep 2011. Arrows indicate direction of animal movement.

TABLE 5.6. Comparison of mean seal CPA distances by seismic status from the *Duke* during Statoil's site survey, 6 Aug – 23 Sep 2011. The overall mean includes CPA distances from seismic status bins.

Seismic Status	Mean CPA[a] (m)	s.d.	Range (m)	*n*
Seismic	491	478	136-2961	***57***
Non-Seismic	300	151	123-619	***29***
Overall	***426***	***408***	***123-2961***	***86***

[a] CPA=Closest Point of Approach. For *Duke* this value is the marine mammal's closest point of approach to the airgun array.

Seal Movement

Most of the seal movements recorded during Statoil's site survey were neutral relative to the vessel (~57%; Table 5.7). Nearly twice as many seals were seen swimming away than swimming towards the *Duke*.

Seal Initial Behavior

Most of the seals observed from the *Duke* (~66%) were recorded to be swimming at the surface when first detected (Table 5.8).

Seal Reaction Behavior

Seals observed from the *Duke* were most often recorded as having no reaction (~48%), while the second-most observed reaction was of seals looking at the vessel (~35%; Table 5.9).

TABLE 5.7. Number of seal sightings by movement relative to vessels by seismic status from the *Duke* during Statoil's site survey, 6 Aug – 23 Sep 2011.

Seismic Status	Movement Relative to Vessel				
	Swim Towards	Swim Away	Neutral	None	*Totals*
Seismic	8	18	35	9	***70***
Non-Seismic	6	12	20	1	***39***
Totals	***14***	***30***	***55***	***10***	***109***

TABLE 5.8. Comparison of seal behaviors by seismic status from the *Duke* during Statoil's site survey, 6 Aug – 23 Sep 2011.

Seismic Status	**Initial Behavior**								
	Dive	**Porpoising**	**Looking**	**Breaching**	**Resting**	**Swim**	**Thrash**	**Other**	**Totals**
Seismic	6	1	16	1	0	42	3	1	***70***
Non-seismic	5	0	8	0	1	22	3	0	***39***
Totals	***11***	***1***	***24***	***1***	***1***	***64***	***6***	***1***	***109***

TABLE 5.9. Comparison of seal reactions to vessel by seismic status from the *Duke* during Statoil's site survey, 6 Aug – 23 Sep 2011.

Seismic Status	**Reaction**						
	Splash	**Increase in Speed**	**Change in Direction**	**Look at Vessel**	**None**	**Unknown**	***Totals***
Seismic	2	4	8	22	34	0	***70***
Non-Seismic	2	0	3	18	15	1	***39***
Totals	***4***	***4***	***11***	***40***	***49***	***1***	***109***

Pacific Walruses

Pacific Walrus Initial Sighting Distance and Distribution

The mean initial sighting distance of Pacific walruses observed from the *Duke* was significantly greater during seismic periods than during non-seismic periods also suggesting some avoidance of the immediate area around the airguns (W=188, p = 0.03, power [1-β] = 0.36; Table 5.10). Pacific walruses were observed as close as 30 m (33 yd) and as far as 2863 m (3131 yd) from the *Duke*.

TABLE 5.10. Comparison of mean Pacific walrus initial sighting distances by seismic status from the *Duke* during Statoil's site survey, 6 Aug – 23 Sep 2011.

Seismic Status	Mean Initial Sighting Distance (m)	s.d.	Range (m)	*n*
Seismic	812	576	40-2863	***33***
Non-Seismic	475	342	30-1298	***18***
Overall	***693***	***528***	***30-2863***	***51***

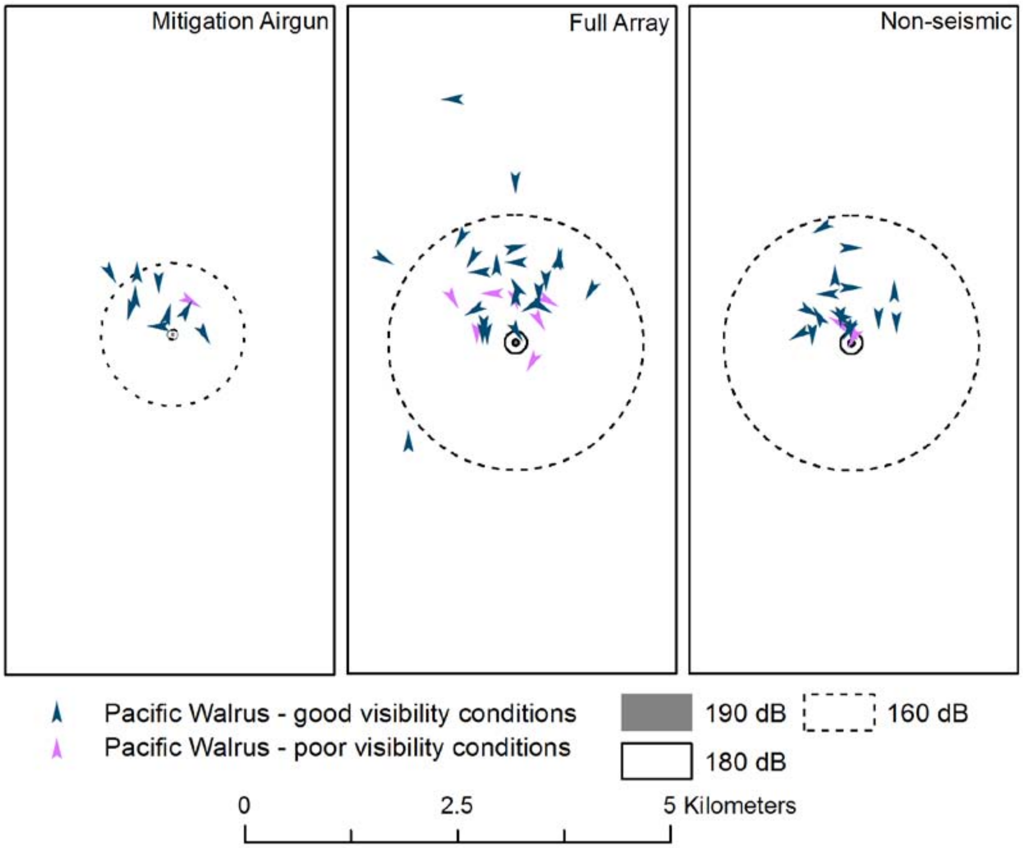

FIGURE 5.17. Initial Pacific walrus sightings from the *Duke* by airgun status with safety radii, during Statoil's site survey, 6 Aug – 23 Sep 2011. A rrows indicate direction of animal movement.

Pacific Walrus Closest Point of Approach

The mean closest points of approach of Pacific walruses were 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 C). The mean CPA of Pacific walruses observed from the *Duke* was greater during seismic periods than during non-seismic periods, but the difference was not statistically significant at the p = 0.05 level (W = 204.5, p = 0.07, power [1-β] = 0.24; Table 5.11). Pacific walruses were observed as close as 109 m (119 yd) and as far as 1703 m (1862 yd) from the *Duke*.

Pacific Walrus Movement

Movements neutral relative to the vessel were the most commonly recorded movements of Pacific walrus from the *Duke* during Statoil's site survey (Table 5.12). The second most frequently observed movement of walrus was swim towards the vessel (~25%).

TABLE 5.11. Comparison of mean Pacific walrus CPA distances by seismic status from the *Duke* during Statoil's site survey, 6 Aug – 23 Sep 2011.

Seismic Status		Mean CPA[a] (m)	s.d.	Range (m)	*n*
Seismic		556	336	116-1703	***33***
Non-Seismic		370	258	109-1135	***18***
	Overall	***490***	***321***	***116-1703***	***51***

[a] CPA=Closest Point of Approach. For *Duke* this value is the marine mammal's closest point of approach to the airgun array.

TABLE 5.12. Number of Pacific walrus sightings by movement relative to vessels by seismic status from the *Duke* during Statoil's site survey, 6 Aug – 23 Sep 2011.

Seismic Status		Movement Relative to Vessel				
		Swim Towards	Swim Away	Neutral	None	*Totals*
Seismic		10	7	20	4	***41***
Non-Seismic		5	6	9	0	***20***
	Totals	***15***	***13***	***29***	***4***	***61***

Pacific Walrus Initial Behavior

Most of the initial behaviors recorded for walrus (~61%) observed from the *Duke* were of animals swimming, while ~26% were initially observed looking at the vessel (Table 5.13). Besides swimming and looking, the *Duke* also recorded initial behaviors of diving (~8%), blowing (~2%), and breaching (~2%).

Pacific Walrus Reaction Behavior

Walruses observed from the *Duke* were most often recorded has having no reaction (~39%) to the vessel or airguns. The second-most observed reaction (~31%) was of walruses looking at the vessel (Table 5.14).

TABLE 5.13. Comparison of Pacific walrus behaviors by seismic status from the *Duk*e during Statoil's site survey, 6 Aug – 23 Sep 2011.

Seismic Status	Initial Behavior						
	Dive	Looking	Blow	Breach	Swim	Other	Totals
Seismic	4	12	0	1	24	0	***41***
Non-Seismic	1	4	1	0	13	1	***20***
Totals	***5***	***16***	***1***	***1***	***37***	***1***	***61***

TABLE 5.14. Comparison of Pacific walrus reactions to vessel by seismic status from the *Duke* during Statoil's site survey, 6 Aug – 23 Sep 2011.

Seismic Status	Reaction						
	Splash	Increase in Speed	Look at Vessel	Change in Direction	None	Unknown	*Totals*
Seismic	2	1	12	11	14	1	***41***
Non-Seismic	1	1	7	1	10	0	***20***
Totals	***3***	***2***	***19***	***12***	***24***	***1***	***61***

Mitigation Measures Implemented

Safety and Disturbance Radii

Prior to completion of the sound source verification measurements, MMOs on the Statoil vessels used the modeled safety radii presented in Statoil's 2011 IHA application and outline in the IHA issued by NMFS for mitigation purposes (see Table 4.1). Statoil's site specific sound source verification (SSV) was completed on 8 Aug 2011 and the results were reported on 14 Aug 2011 (Warner et. al. 2011). The preliminary radii distances shown in Table 4.1 were implemented for mitigation purposes beginning on 14 Aug and throughout the duration of the survey. There were no differences between the preliminary safety radii distances and the final safety radii distances.

Sightings that occurred during Ramp-up Periods

There were 17 total marine mammal sightings during ramp up periods. All sightings were of pinnipeds: six Pacific walrus, one ringed seal, four bearded seals, three unidentified pinnipeds, and three unidentified seals (Table 5.16). The fastest pace of marine mammals sighted during ramp up was moderate, and no comments made during ramp up periods describe agitation or abnormal behavior. Of these sightings, ~41% exhibited no reaction to the vessel, ~41% looked at the vessel, ~6% (1 individual) splashed, and ~12% (2 individuals) changed direction (Table 5.17). These reactions are similar in proportion to reactions during seismic and non-seismic activity. Sighting rates for pinnipeds during ramp up periods were similar to those during seismic and non-seismic periods; however, the sighting rate during ramp up periods should be viewed with some caution due to the limited amount of time that ramp-ups were occurring relative to the other two periods, and therefore the total MMO watch effort during ramp-ups was limited (Fig. 5.17).

TABLE 5.16. Comparison of reactions during ramp up by species to reactions by seismic status from the *Duke* during Statoil's site survey, 6 Aug – 23 Sep 2011.

Species	**Pace**				
	Sedate	**Moderate**	**Vigorous**	**Unknown**	***Totals***
Bearded Seal	0	4	0	0	***4***
Ringed Seal	1	0	0	0	***1***
Pacific Walrus	3	3	0	0	***6***
Unidentified Pinniped	0	2	0	1	***3***
Unidentified Seal	0	3	0	0	***3***
Totals	***4***	***12***	***0***	***1***	***17***

TABLE 5.17. Comparison of reactions during ramp up by species to reactions by seismic status from the *Duke* during Statoil's site survey, 6 Aug – 23 Sep 2011.

Seismic Status	**Reaction**						
	Splash	**Increase in Speed**	**Change in Direction**	**Look at Vessel**	**None**	**Unknown**	***Totals***
Ramp Up	1	0	2	7	7	0	***17***
Seismic	2	4	8	22	34	0	***70***
Non-Seismic	2	0	3	18	15	1	***39***
Seismic Status Totals	***5***	***4***	***13***	***47***	***56***	***1***	***126***

Mitigation Actions

A total of three power downs, one shutdown, and one delayed ramp up were requested during the Statoil site survey as a result of marine mammal sightings within or approaching the applicable safety radius. All of these mitigation actions resulted from Pacific walrus sightings.

Three power downs were requested and implemented for Pacific walruses observed within or about to enter the ≥180 dB (rms) safety radius around the full 40 in^3 airgun array. All power downs occurred during a 2-day period, 17–19 Aug, when walrus sightings were most numerous. Each of the power downs occurred when the array was operating at full volume (40 in^3). None of the walrus that caused the power downs were seen within the safety radius of the mitigation airgun, so no shut downs were requested for sightings of live animals.

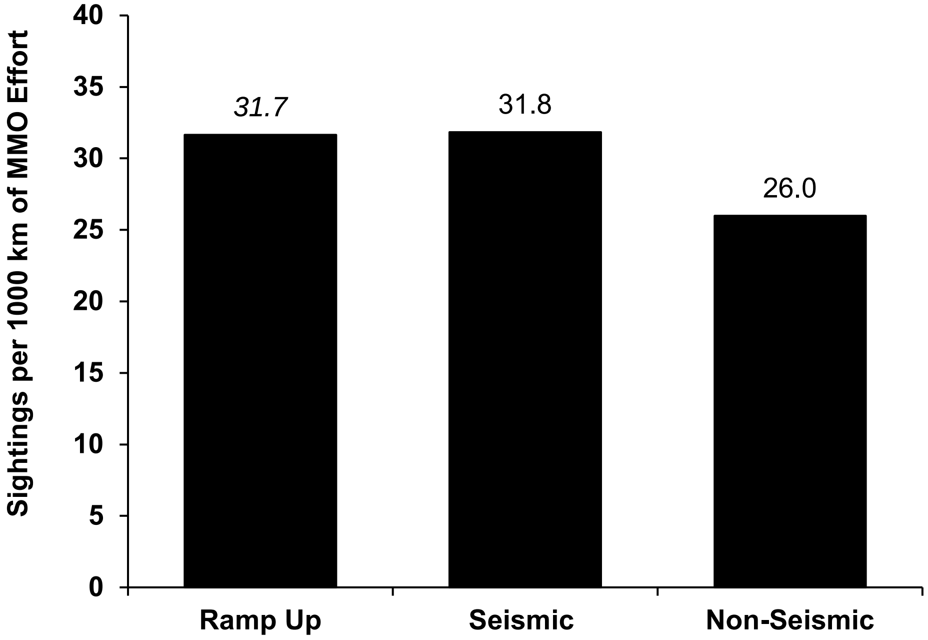

FIGURE 5.17. Sighting rates for all pinniped sightings *Duke* by airgun status from the *Duke* during Statoil's site survey, 6 Aug – 23 Sep 2011. Italicized numbers indicate that the sighting rate may not be reliable due to a limited amount of observation effort having occurred within the category.

In addition to the three power downs, one complete shutdown was implemented during the seismic survey. The shutdown occurred on 15 Aug for an unidentified pinniped carcass which was later determined to be a Pacific walrus carcass. Once it was determined by MMOs aboard the *Duke* that the death had not occurred as a result of the seismic activities (i.e. the amount of decomposition on the animal indicated that it had been dead for some time, as it was missing large patches of skin and flesh), permission was granted to resume the seismic survey.

One delayed ramp up occurred when MMOs were unsure whether two adult Pacific walruses had entered or were about to enter the ≥180 dB (rms) safety radius around the full 40 in^3 airgun array shortly before a ramp-up was to begin. The sighting occurred on 18 Aug when two Pacific walruses, ~308 m (337 yd) away from the vessel, appeared to move towards the vessel as they dove. Ramp up was allowed to proceed once MMOs resighted the walruses moving away from the vessel and outside of the ≥180 dB (rms) safety radius.

Estimated Number of Marine Mammals Present and Potentially Affected

It is often difficult to obtain meaningful estimates of "take by harassment" 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 (RSL) reaches a specific criterion such as 190 dB, 180 dB, 160 dB, or 120 dB re 1 µPa (rms) is variable. The RSL 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 (seal and Pacific walrus) and cetacean densities obtained during this study. The actual number of individuals exposed to, and potentially impacted by, seismic survey sounds or coring 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.

Disturbance and Safety Criteria

Table 4.1 summarizes estimated RSLs at various distances from *Duke's* 4-airgun cluster. The NMFS required that distances to RSLs of 180 dB and 190 dB (rms) be used to implement mitigation measures for cetaceans and seals respectively. The USFWS required that distances to RSLs of 180 dB and 190 dB (rms) be used to implement mitigation measures for Pacific walruses and polar bears, respectively. Both agencies assume that disturbance to marine mammals from pulsed airgun sounds may occur at RSLs ≥160 dB (rms).

Estimates from Direct Observations

All sightings data were included in the following exposure estimates based on direct observations, regardless of whether they met the data-analysis criteria described in Chapter 4. The number of animals actually sighted by observers within the various sound level distances during seismic activity provides 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. Other animals, even if they surface near the vessel, are missed because of limited visibility (e.g. fog), glare, or other factors limiting sightability. Furthermore, marine mammals could not be seen effectively during periods of darkness, which increased as the survey progressed. 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 *Duke* stayed on watch throughout the night to monitor survey operations.

Animals may also have avoided the area near the *Duke* while the airguns were firing (see Richardson et al. 1995, 1999; Stone and Tasker 2006; 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 *Duke* 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). It was not possible to determine if cetaceans exhibited avoidance behavior beyond the distance at which they were detectable by MMOs.

Cetaceans Potentially Exposed to Received Sound Level ≥160 and ≥180 dB re 1 μPa (rms)

One cetacean sighting occurred from the *Duke* during a seismic period and only the mitigation airgun was operating at that time. The closest point of approach of the individual to the airgun was 1105 m (1208 yd) and the ≥180 dB (rms) safety radius for the mitigation airgun was 59 m (65 yd; Table 4.1). The ≥160 dB (rms) distance from the mitigation airgun was 840 m, so the individual was not likely exposed to seismic sounds ≥160 dB (rms).

Seals Potentially Exposed to Received Sound Level ≥160 dB and ≥190 dB re 1 μPa (rms)

Seventy two seals were observed from the *Duke* while airguns were operating and 68 of these individuals were likely exposed to received sound levels ≥160 dB (rms). However, no seal sightings occurred within the ≥190 dB safety radius, so no mitigation measures were requested.

Pacific Walruses Potentially Exposed to Received Sound Level ≥160 dB and ≥180 dB re 1 μPa (rms)

Sixty-two Pacific walrus sightings were observed from the *Duke* while airguns were operating and of these, 57 walruses were likely exposed to received sound levels ≥160 dB (rms). Based on the final SSV measurement results, two walruses in two separate sightings were likely exposed to RSLs ≥180 dB (rms). Power downs were requested and implemented in both cases.

Estimates Extrapolated from Density

The number 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 detected 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 during those two periods. The estimated densities of marine mammals were then multiplied by the area of water ensonified (exposed to seismic sounds) to estimate the number of individual marine mammals exposed to received sound levels (RSL) ≥160 dB (rms). Because the site survey transect lines were spaced closer together than twice the measured ≥160 dB distance (2 × 1.5 km = 3.0 km; see Appendix I for weekly maps of the survey activity), the same area of water at the survey site would have been exposed to seismic sounds multiple times as the vessel surveyed the nearby transect lines. The ratio of the total area exposed to seismic sounds including multiple counts of areas exposed more than once to the area of water exposed excluding multiple counts was 11.1 in Aug, 9.2 in Sep, and 16.3 overall. These represent the average number of exposures per individual marine mammal present in the survey area if the individual had remained present through that period of time.

Marine mammal densities were based on data collected from both the *Duke* and *Synergy* during Statoil's site survey and geotechnical coring operations in the Chukchi Sea. The density estimates for the Statoil survey area were calculated separately by season, summer (August) and fall (September), for consistency with the NMFS IHA application take estimates and are summarized in Tables 5.18 and 5.19. The area of water exposed to various sound levels are shown in Table 5.20. The methodology used to estimate the areas exposed to RSLs ≥120, 160, 170, 180 and 190 dB (rms) was described in Chapter 4 and in more detail in Appendix C.

The following estimates based on density calculations assume that all mammals present were well below the surface where they were exposed to RSLs at various distances as reported in Chapter 3 and summarized in Table 4.1. 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 *Duke* as it was surveying in an avoidance response to the approaching vessel and airgun sounds. In the case of cetaceans and walrus, the total estimated number of exposures based on non-seismic densities represents the number of animals that would have been exposed had they not shown any avoidance of the airguns or the ship.

Cetaceans

Tables 5.21, 5.22, and 5.23 summarize the estimated numbers of cetaceans that may have been exposed to seismic sounds at received levels ≥160 dB (rms) based on the density estimates in Tables 5.18 and 5.19, and the ensonified areas in Table 5.20. Higher sighting rates, and resulting density estimates, during non-seismic periods than during seismic periods from the *Duke* (Fig. 5.9) suggest that some cetaceans may have moved away from the seismic source before being exposed to strong sounds. However, most cetacean sightings from the *Duke* occurred during transit to and from Wainwright, so the difference in sighting rates and densities between seismic and non-seismic periods may actually be a result of the overall distribution of cetaceans in the Chukchi Sea and not seismic sounds.

Approximately 21 individual cetaceans, mostly gray whales, would each have been exposed to airgun pulses with RSLs ≥160 dB (rms) during the survey if they showed no avoidance of active airguns or vessels (Table 5.23). The lower densities of cetaceans observed during seismic periods suggests that some such avoidance may have occurred. Therefore, the estimate based on non-seismic densities likely overestimates the actual number of animals exposed to sounds ≥160 dB (rms). However, it is important to note that nearly all cetacean sightings occurred during transit to or from Wainwright, away from the site survey location. Thus, the non-seismic densities are likely an overestimate of the number of animals that would have been present in the survey area with or without site survey activities.

TABLE 5.18. Summer (Aug) densities of marine mammals in the Alaskan Chukchi Sea observed during Statoil's site survey and geotechnical coring, 6 Aug – 27 Sep 2011. Densities are corrected for *f*(0) and *g*(0) biases (see Appendix C).

	No. individuals / km^2					
	Seismic			Non-seismic		
Species	**Density**	**LCL**	**UPC**	**Density**	**LCL**	**UPC**
Cetaceans						
Gray whale	0.000	--	--	0.020	0.005	0.058
Unid. mysticete whale	0.000	--	--	0.004	0.001	0.033
Total Cetaceans	***0.000***	***--***	***--***	***0.024***	***0.008***	***0.085***
Seals						
Ringed Seal	0.041	0.010	0.084	0.042	0.009	0.194
Spotted Seal	0.003	0.001	0.029	0.000	--	--
Bearded Seal	0.020	0.020	0.064	0.046	0.011	0.101
Unid. Seal	0.022	0.002	0.154	0.040	0.009	0.190
Unid. Pinniped	0.008	0.001	0.129	0.004	0.000	0.026
Total Seals	***0.094***	***0.028***	***0.339***	***0.133***	***0.019***	***0.558***
Pacific walrus	0.078	0.028	0.298	0.120	0.042	0.378

TABLE 5.19. Fall (Sep) densities of marine mammals in the Alaskan Chukchi Sea observed during Statoil's site survey and geotechnical coring, 6 Aug – 27 Sep 2011. Densities are corrected for *f*(0) and *g*(0) biases (see Appendix C).

	No. individuals / km^2					
	Seismic			Non-seismic		
Species	**Density**	**LCL**	**UPC**	**Density**	**LCL**	**UPC**
Cetaceans						
Gray whale	0.000	--	--	0.001	0.000	0.013
Unid. mysticete whale	0.000	--	--	0.001	0.000	0.003
Total Cetaceans	***0.000***	***--***	***--***	***0.002***	***0.001***	***0.013***
Seals						
Ringed Seal	0.022	0.006	0.074	0.005	0.000	0.062
Spotted Seal	0.000	--	--	0.000		
Bearded Seal	0.111	0.031	0.507	0.014	0.001	0.078
Unid. Seal	0.014	0.001	0.169	0.007	0.000	0.069
Unid. Pinniped	0.013	0.001	0.125	0.007	0.001	0.072
Total Seals	***0.160***	***0.058***	***0.448***	***0.033***	***0.005***	***0.113***
Pacific walrus	0.035	0.009	0.164	0.059	0.012	0.259

Seals

Tables 5.21, 5.22, and 5.23 summarize the estimated numbers of seals potentially exposed to RSLs ≥160 dB (rms) during the site survey. Avoidance of seismic surveys may not always occur or be detected; however, localized avoidance of seismic operations by seals has been observed in some cases (Reiser 2009). The higher sightings rates, and corresponding density estimates of seals during seismic periods than during non-seismic periods during fall (Table 5.19) suggests that seals did not necessarily avoid airgun sounds. However, analysis of initial detection distances and CPAs earlier in this chapter suggest that some level of avoidance may have occurred.

Density based calculations result in an estimate that ~169 individual seals may have been exposed to airgun pulses with RSLs ≥160 dB (rms) during the survey, assuming no avoidance of the ≥160 dB (rms) radius (Table 5.23). This may have included ~80 bearded seals, ~46 ringed seals, ~3 spotted seals. Since not all pinnipeds could be identified to species by the observers, the density based estimates also include ~42 individual pinnipeds of unknown species.

Pacific walruses

Tables 5.21, 5.22, and 5.23 summarize the estimated number of Pacific walruses potentially exposed to RSLs ≥160 dB (rms) during the site survey. Pacific walrus sighting rates and densities during seismic periods were lower than those observed during non-seismic periods suggesting that walrus may have avoid the airgun sounds at distances beyond which observers could detect them. However, most walrus sightings occurred during two separate periods and locations (Fig 5.15). One was on the survey site during a period of seismic activity and the other was offshore of Wainwright while the vessel was in transit for a crew change. Together, these encounters may have had a greater impact on the calculated densities of walrus than did any potential avoidance reaction.

The density based calculations result in an estimate of ~132 individual walruses having been potentially exposed to airgun pulses with RSLs ≥160 dB (rms) during the survey, assuming no avoidance of the ≥160 dB (rms) radius (Table 5.23).

TABLE 5.20. Estimated areas (km^2) ensonified to various sound levels during Statoil's site survey, 6 Aug – 23 Sep 2011.

		Level of ensonification in dB re 1 µPa (rms)				
	Area (km^2)	**190**	**180**	**170**	**160**	**120**
Summer	Including Overlap Area	184	667	2,483	9,010	237,668
	Excluding Overlap Area	135	296	510	809	7,467
Fall	Including Overlap Area	108	390	1,448	5,246	133,861
	Excluding Overlap Area	91	240	375	573	6,121

TABLE 5.21. Estimated numbers of individual marine mammals exposed to pulsed seismic sounds at received levels of ≥160 dB (rms) based on densities observed during seismic and non-seismic periods in summer (Aug) of Statoil's 2011 site survey, 6 Aug – 23 Sep 2011. All fractional values in the table have been rounded up to the nearest whole number. The totals for cetaceans and seals were calculated on the sum of the densities within that group, not the sum of the rounded estimates for each species.

	Estimated No. Individuals						**Requested Take**	
	Seismic Densities			**Non-seismic Densities**				
Species	**Mean**	**LCL**	**UCL**	**Mean**	**LCL**	**UCL**	**Mean**	**Max**
Cetaceans								
Gray whale	0	–	–	17	5	48	13	27
Unid. mysticete whale	0	–	–	4	1	27	–	–
Total Cetaceans	***0***	***--***	***--***	***20***	***7***	***69***	16	31
Seals								
Ringed Seal	33	8	69	35	8	157	196	325
Spotted Seal	3	1	24	0	–	–	4	7
Bearded Seal	17	17	53	38	10	82	6	10
Unid. Seal	19	2	125	33	8	154	–	–
Unid. Pinniped	7	1	105	4	1	22	–	–
Total Seals	***77***	***23***	***275***	***108***	***16***	***452***	206	344
Pacific walrus	63	23	242	98	34	306	–	–

TABLE 5.22. Estimated numbers of individual marine mammals exposed to pulsed seismic sounds at received levels of ≥160 dB (rms) based on densities observed during seismic and non-seismic periods in fall (Sep) of Statoil's 2011 site surveys, 6 Aug – 23 Sep 2011. All fractional values in the table have been rounded up to the nearest whole number. The totals for cetaceans and species were calculated on the sum of the densities within that group, not the sum of the rounded up estimates for each species.

	Estimated No. Individuals						**Requested Take**	
	Seismic Densities			**Non-seismic Densities**				
Species	**Mean**	**LCL**	**UCL**	**Mean**	**LCL**	**UCL**	**Mean**	**Max**
Cetaceans								
Gray whale	0	--	--	1	1	8	5	10
Unid. mysticete whale	0	--	--	1	1	2	--	--
Total Cetaceans	***0***	***--***	***--***	***1***	***1***	***8***	17	34
Seals								
Ringed Seal	13	4	43	4	1	36	140	232
Spotted Seal	0	--	--	0	--	--	3	5
Bearded Seal	64	18	291	9	1	45	6	10
Unid. Seal	8	1	97	4	1	40	--	--
Unid. Pinniped	8	1	72	5	1	42	--	--
Total Seals	***92***	***34***	***257***	***20***	***3***	***65***	149	248
Pacific walrus	21	6	94	34	7	149	--	--

TABLE 5.23. Estimated numbers of individual marine mammals exposed to pulsed seismic sounds at received levels of ≥160 dB (rms) based on densities observed during seismic and non-seismic periods during all of Statoil's 2011 site survey, 6 Aug – 23 Sep 2011. All fractional values in the table have been rounded up to the nearest whole number. The totals for cetaceans and seals were calculated on the sum of the densities within that group, not the sum of the rounded estimates for each species.

	Estimated No. Individuals						**Requested Take**	
	Seismic Densities			**Non-seismic Densities**				
Species	**Mean**	**LCL**	**UCL**	**Mean**	**LCL**	**UCL**	**Mean**	**Max**
Cetaceans								
Gray whale	0	0	0	18	5	39	18	37
Unid. mysticete whale	0	0	0	4	1	8	--	--
Total Cetaceans	***0***	***0***	***0***	***21***	***7***	***48***	32	94
Seals								
Ringed Seal	46	16	106	38	10	84	337	557
Spotted Seal	3	1	6	0	0	0	7	11
Bearded Seal	80	29	188	46	14	105	11	22
Unid. Seal	27	4	57	37	10	82	--	--
Unid. Pinniped	15	2	31	8	2	17	--	--
Total Seals	***169***	***77***	***413***	***127***	***25***	***278***	355	595
Pacific walrus	84	36	202	132	54	317	--	--

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6. MARINE MAMMAL MONITORING RESULTS DURING GEOTECHNICAL CORING OPERATIONS[1]

Monitoring Effort and Marine Mammal Encounter Results

This chapter summarizes the visual observer effort from the *Synergy* during Statoil's 2011 geotechnical coring operations in the Chukchi Sea, and does not include effort conducted during transit from Dutch Harbor to and from the survey area (north of Point Hope, Alaska). The survey period began when the *Synergy* entered the Chukchi Sea survey area on 4 Sep 2011 (AKDT) and ended when the *Synergy* departed the area on 27 Sep 2011.

The *Synergy* traveled along a total of ~1846 km (1147 mi) of trackline in the Chukchi Sea survey area while moving between coring locations or transiting between the survey area and Wainwright. The Synergy was within the survey area for ~556 h. The *Synergy* was stationary in dynamic positioning mode for ~492 h. While in dynamic positioning mode, the Synergy was actively coring for ~283 of those hours.

Vessels other than those involved in Statoil's operations seldom passed through the project area. Each ship that was not participating in the project transited well away from survey activities (>15 km) and MMOs observed no instances of harassment or disturbance to marine mammals due to their presence.

Observer Effort

MMOs aboard the *Synergy* were on watch for a total of ~1094 km (680 mi; 55 h) while the vessels was moving and ~277 h while it was stationary (Figure 6.1). At least one observer was on watch during 100% of daylight hours regardless of vessel activity. At least two MMOs were on watch for ~39% (63 h) of daylight coring operations and three MMOs were on watch for ~5% (10 h) of daylight coring operations. At least one MMO was on duty during the transitional hours between darkness and morning daylight, as well as from dusk until darkness eliminated visibility. During all darkness hours (night time), at least one MMO remained on duty. This MMO did not conduct systematic watches the entire darkness period, but did perform periodic scans of the waters around the *Synergy* with night vision devices.

Observer Effort by Beaufort Wind Force

Observer effort from the *Synergy* occurred between Beaufort wind force (Bf) one and Bf six (Fig. 6.2). The greatest amount of observer effort while moving occurred during Bf four, which accounted for ~34% of MMO effort aboard the *Synergy*. The greatest amount of observer effort while stationary (~26%) occurred during Bf 3. Overall, ~88% of effort while moving and ~76% of effort while stationary occurred in Bf two, three, or four.

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[1] By Sarah Case, Lauren Bisson, Kris Hartin (LGL Alaska Research Associates, Inc.)

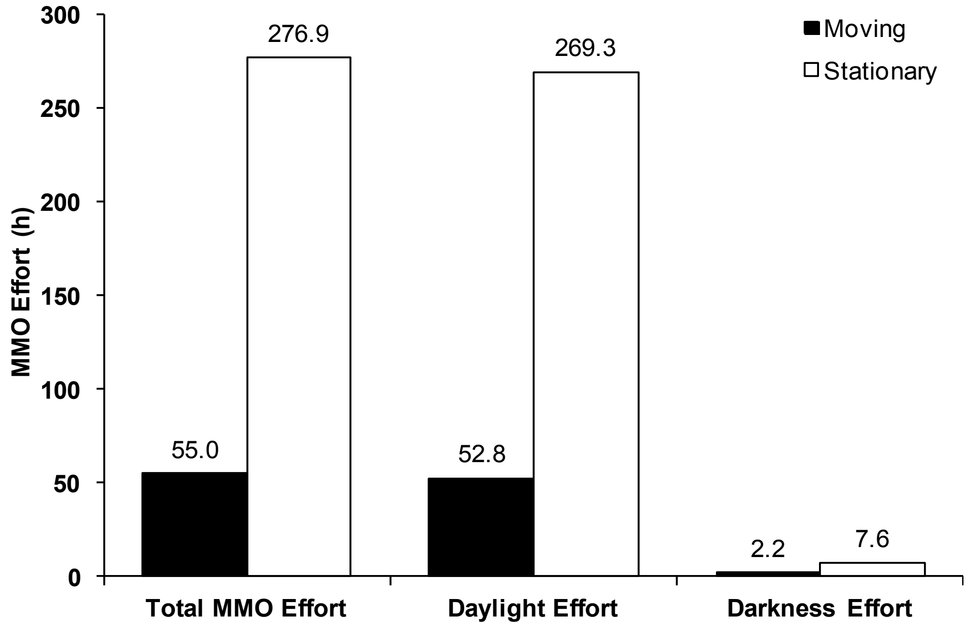

FIGURE 6.1. Total MMO observation effort (h) and MMO effort during daylight and darkness periods from the *Synergy* during Statoil's geotechnical coring operations, 4 Sep – 27 Sep 2011.

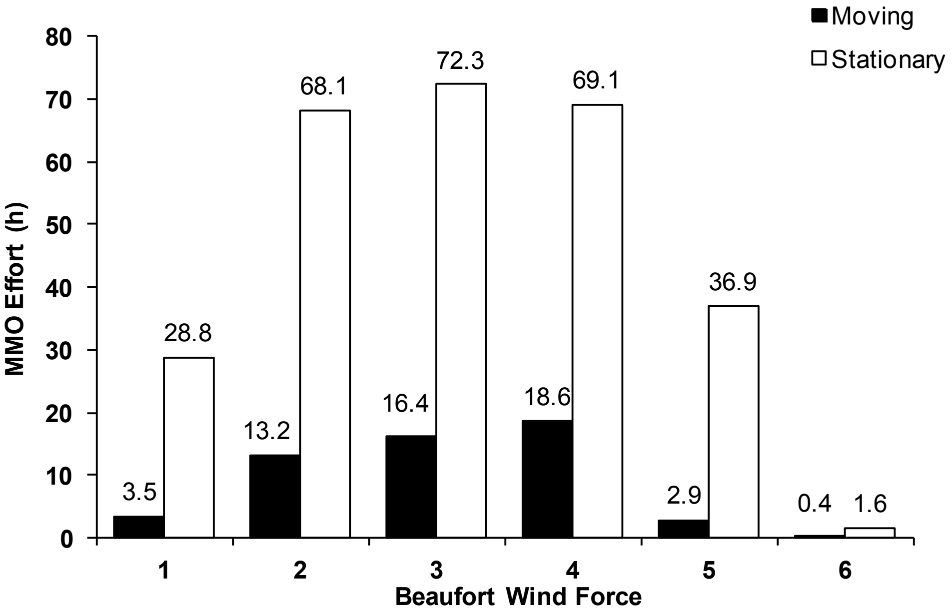

FIGURE 6.2. MMO observation effort (h) by Beaufort wind force from the *Synergy* during Statoil's geotechnical coring operations, 4 Sep – 27 Sep 2011.

Observer Effort by Number of MMOs

On the *Synergy*, two MMOs were on watch during ~32% of observation effort while moving and ~31% of observation effort while stationary (Fig. 6.3). MMOs were scheduled to maximize effort during mid-day hours when optimum visibility conditions were likely to maximize monitoring and mitigation efforts.

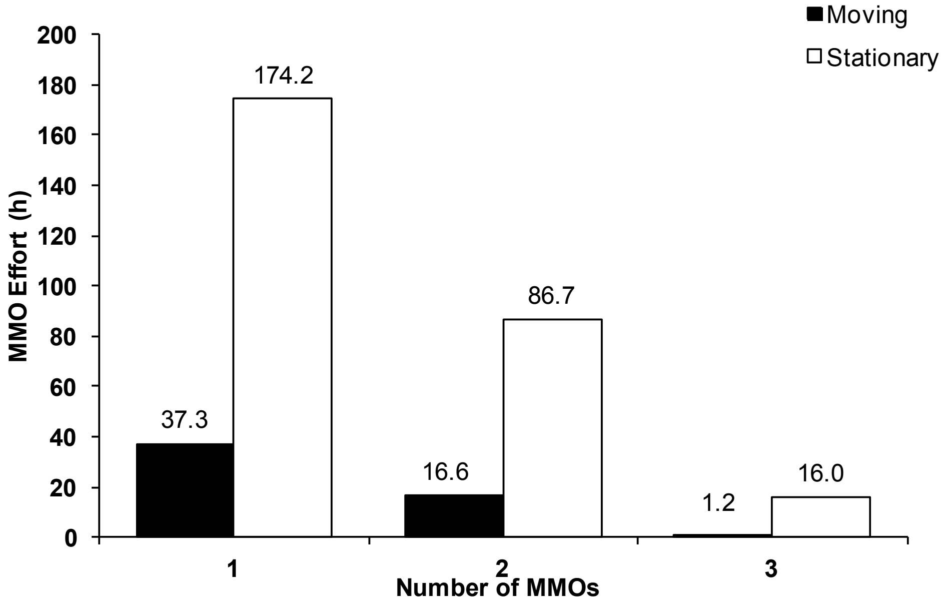

FIGURE 6.3. MMO observation effort (h) for moving and stationary periods by number of MMOs from the *Synergy* during Statoil's geotechnical coring operations, 4 Sep – 27 Sep 2011.

Observer Effort by Visibility Distance

On the Synergy, ~91% of moving and ~85% of stationary effort hours occurred in visibility greater than 3.5 km, which is the threshold criterion for "good visibility conditions" (Fig 6.4 and Fig 6.5). A substantial portion (~21% of moving and ~20% of stationary) of MMO effort occurred during variable visibility > 3.5 km. This category was used by MMOs when frequent but brief snow squalls passed through the area obscuring only portions of overall visibility around the vessel (Fig 6.4 and Fig 6.5).

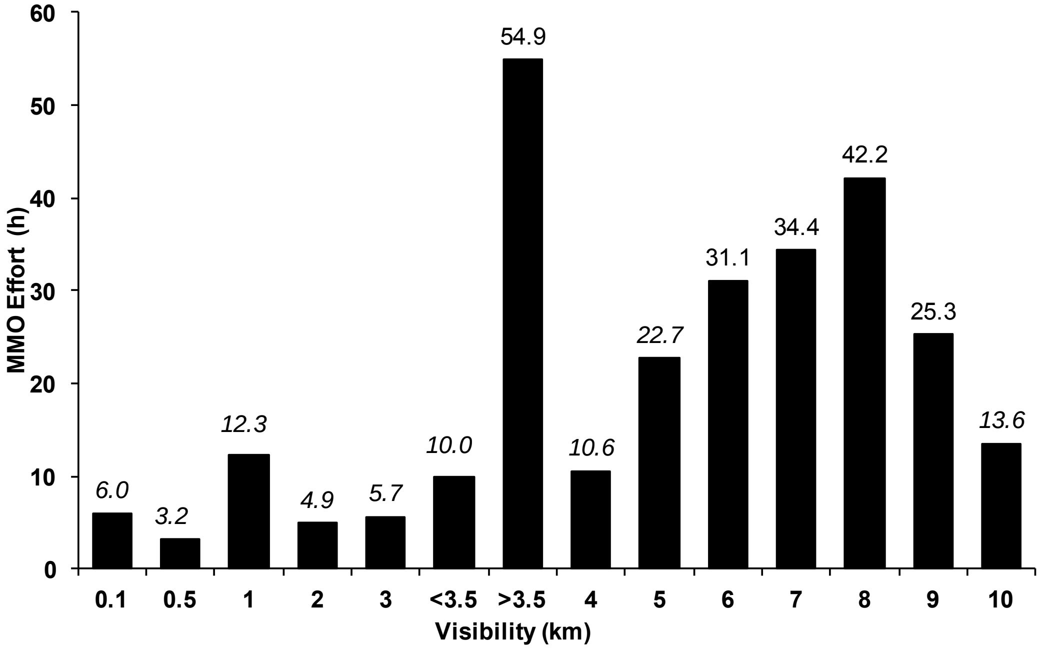

FIGURE 6.4. MMO observation effort (h) for stationary periods by visibility (km) from the *Synergy* during Statoil's geotechnical coring operations, 4 Sep – 27 Sep 2011. Italicized numbers indicate that the sighting rate may not be reliable due to a limited amount of observation effort having occurred within the category.

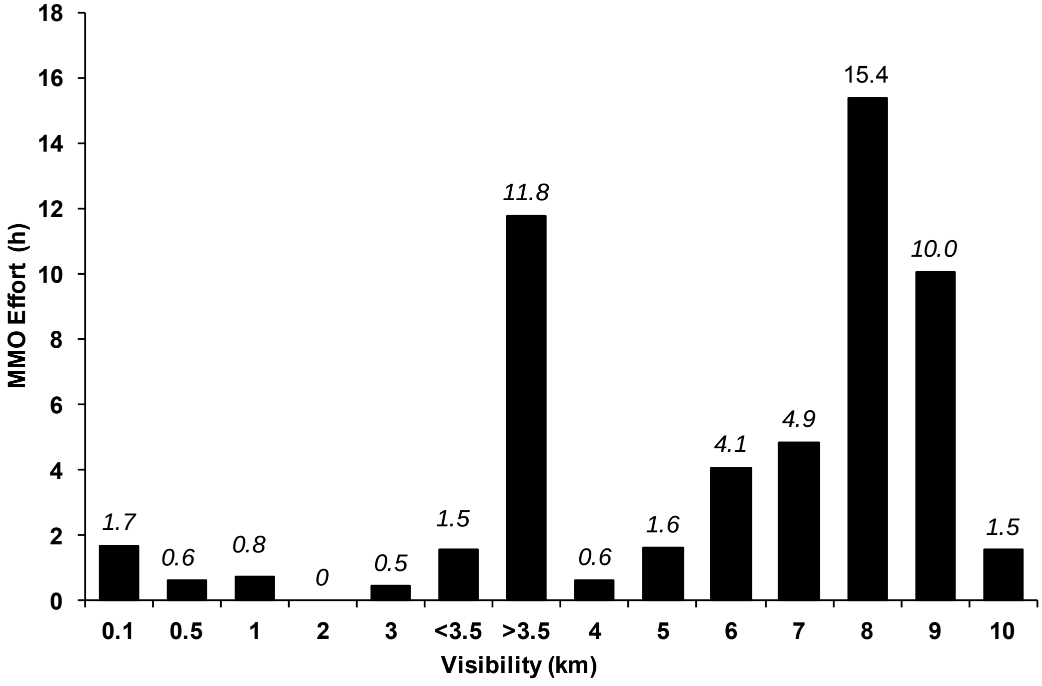

FIGURE 6.5. MMO observation effort (h) for moving periods by visibility (km) from the *Synergy* during Statoil's geotechnical coring operations, 4 Sep – 27 Sep 2011. Italicized numbers indicate that the sighting rate may not be reliable due to a limited amount of observation effort having occurred within the category.

Observer Effort by Vessel Activity

Most observer effort from the *Synergy* while stationary occurred during coring operations (~68%; Fig. 6.4). The majority of 'other' operations shown in Fig 6.4 were periods of vessel transit within the survey area. A small percentage of movement/transit time occurred while the vessel remained in dynamic positioning mode when borehole target locations were relatively close together (~1%; Fig. 6.4)

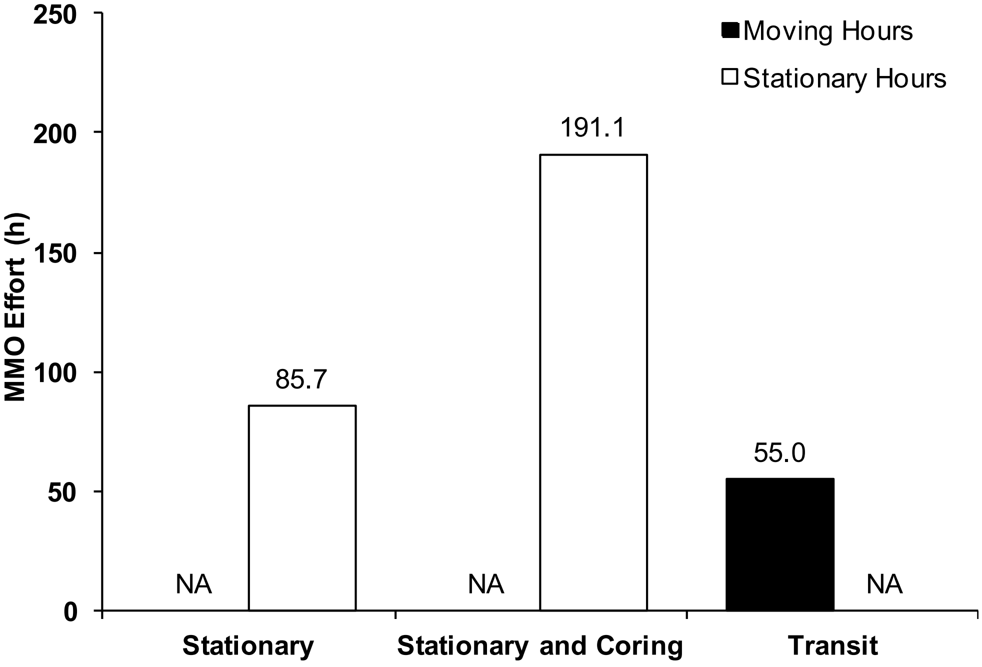

FIGURE 6.6. MMO observation effort (h) by vessel activity from the *Synergy* during Statoil's geotechnical coring operations, 4 Sep – 27 Sep 2011.

Marine Mammal Sightings

During the Statoil geotechnical coring operations, MMOs observed a total of 36 sightings of 68 marine mammals from the *Synergy*. Details of each marine mammal sighting observed in the survey area are available in Appendix G. The sighting data below are presented in three species groups: cetaceans, seals, and Pacific walruses. No polar bears were observed during the activities.

Cetacean Sightings

MMOs observed 5 sightings of 8 cetaceans from the *Synergy* (Table 6.1). The majority of sightings occurred during transits to and from Wainwright. Only one cetacean was observed from the *Synergy* while at the project site on Statoil's leases.

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 C) and the sightings that occurred during those periods. Data that met these criteria are presented in Parts 2 and 3 of Appendix F.

TABLE 6.1. Number of cetacean sightings (number of individuals) from the *Synergy* during Statoil's geotechnical coring operations, 4 Sep – 27 Sep 2011.

Species	**Moving**	**Stationary**	**Stationary and Coring**	**Sightings (Individuals)**
Cetaceans				
Gray Whale	2 (4)	0 (0)	0 (0)	*2 (4)*
Unidentified Mysticete Whale	2 (3)	1 (1)	0 (0)	*3 (4)*
Total Cetaceans	***4 (7)***	***1 (1)***	***0 (0)***	***5 (8)***

Cetacean Sighting Rates by Beaufort Wind Force – Only two cetacean sightings were considered "useable" for calculating sightings rates by Beaufort wind force, as all others occurred during hours of near-darkness and/or poor visibility that did not meet the data analysis criteria. One sighting occurred in Bf 2 and the other in Bf 4. This limited sample size does not allow for meaningful comparison across a full range of Beaufort wind force conditions.

Cetacean Sighting Rates by Visibility – Of the two sightings that met the data analysis criteria, one occurred in variable visibility greater than 3.5 km and the other in excellent visibility of 8 km. This limited sample size does not allow for meaningful comparison across a full range of visibility conditions.

Cetacean Sighting Rates by Number of MMOs – The two cetacean sightings that met the data analysis criteria both occurred when one MMO was on watch and during transits to and from Wainwright. The three unusable cetacean sightings also occurred when only one MMO was on watch. This limited sample size does not allow for meaningful comparison of number of MMOs on watch.

Cetacean Sighting Rates by Vessel Activity – The two useable cetacean sightings both occurred during transits two and from Wainwright. Two of the cetacean sightings that occurred during poor visibility conditions also occurred during transits. The one sighting that occurred at the project area was detected in poor visibility conditions while the *Synergy* was stationary in dynamic positioning mode. This limited sample size does not allow for meaningful comparison among vessel activities.

Seal Sightings

There were 12 seal sightings of 12 individuals by MMOs on the *Synergy* (Table 6.2). Eight of these sightings occurred while the *Synergy* was moving, and four of the sightings occurred while it was stationary. The majority of seal sightings could not be identified to species (~83%; Table 6.2).

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 C) and the sightings that occurred during those periods.

TABLE 6.2. Number of seal sightings (number of individuals) from the *Synergy* during Statoil's geotechnical coring operations, 4 Sep – 27 Sep 2011.

Species	**Moving**	**Stationary**	**Stationary and Coring**	**Sightings (Individuals)**
Seals				
Ringed Seal	0 (0)	0 (0)	2 (2)	*2 (2)*
Unidentified Pinniped	3 (3)	1 (1)	1 (1)	*5 (5)*
Unidentified Seal	5 (5)	0 (0)	0 (0)	*5 (5)*
Total Seals	***8 (8)***	***1 (1)***	***3 (3)***	***12 (12)***

Seal Sighting Rates by Beaufort Wind Force **–** Seal sighting rates from the *Synergy* while moving were greatest during periods of Bf two, however, there was limited MMO effort during in those conditions (Fig. 6.5). Seal sighting rates from the *Synergy* while stationary were greatest during Bf one, although there was limited MMO effort under those conditions as well. As would be expected, most seal sightings from the *Synergy* occurred on days with lower average daily Beaufort wind force (Fig. 6.7).

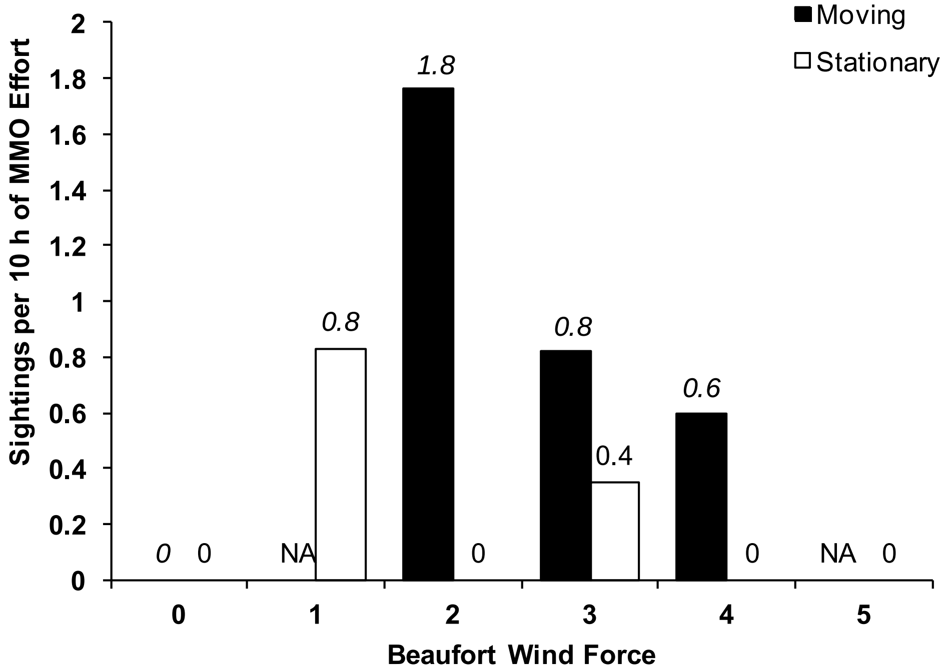

FIGURE 6.7. Seal sighting rates by Beaufort wind force level from the *Synergy* during Statoil's geotechnical coring operations, 4 Sep – 27 Sep 2011. NA indicates that there was insufficient effort in the category to calculate a sighting rate. Italicized numbers indicate that the sighting rate may not be reliable due to a limited amount of observation effort having occurred within the category.

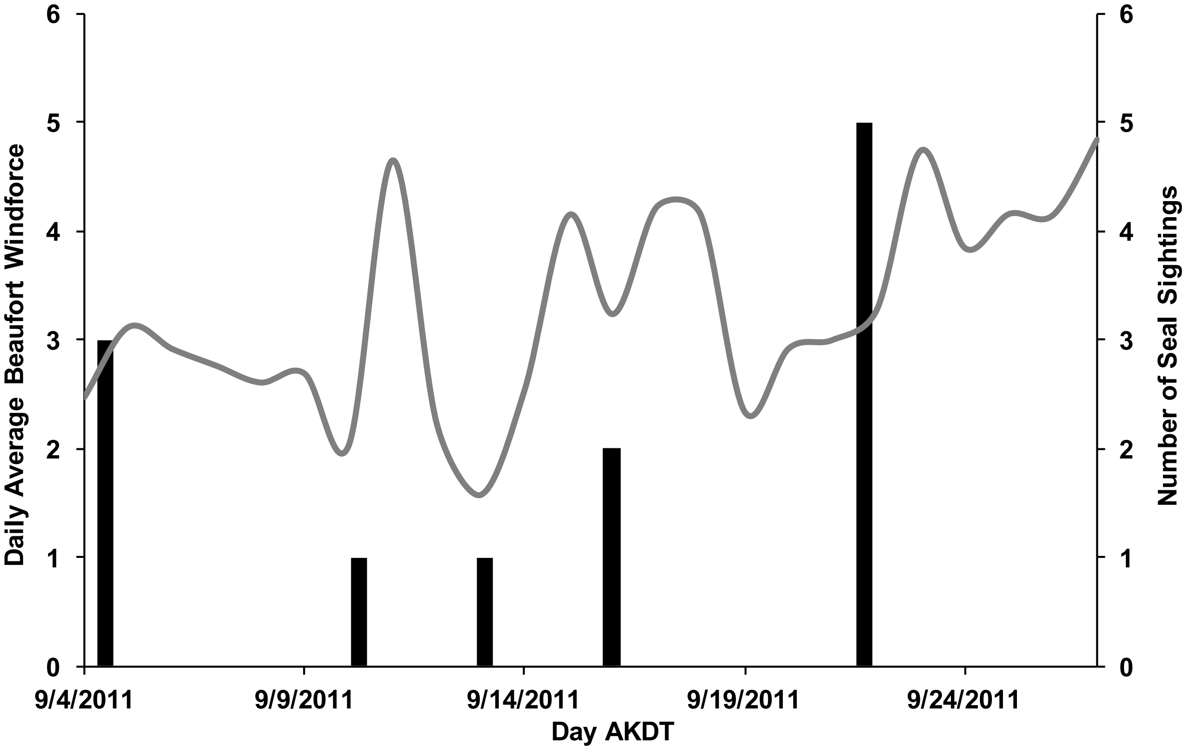

FIGURE 6.8. Seal sightings during daily average Beaufort wind force conditions from the *Synergy* during Statoil's geotechnical coring operations, 4 Sep – 27 Sep 2011.

Seal Sighting Rates by Visibility Distance – Seal sighting rates showed no apparent trend when grouped by visibility (Fig. 6.7). However, due to limited MMO effort in several visibility categories and an overall low number of seal sightings, interpretation of the resulting sighting rates should be done with caution. With that in mind, most seal sightings tend to occur relatively close to the vessel as the sighting cue is typically a head or splash not visible at great distances from the vessel. If seas are calm around the vessel during periods when visibility distance is reduced (>2-3 km) a similar sighting rate to periods when visibility distance is very good (>7 km) might be expected since most seals tend to be observed within 2 km of the vessel. Thus, seal sighting rates may be influenced more by Bf state than visibility distance, as long as visibility distance is greater than one to two km.

Seal Sighting Rates by Number of MMOs – While the vessel was stationary, seal sighting rates with two MMOs on watch were four times greater than with one MMO on watch. While the *Synergy* was moving, the seal sighting rate with two MMOs on watch was twice that when only one MMO was on watch. However, limited effort (30 h, 15 h respectively) occurred for both moving vessel values, so those sighting rates should be viewed with some caution.

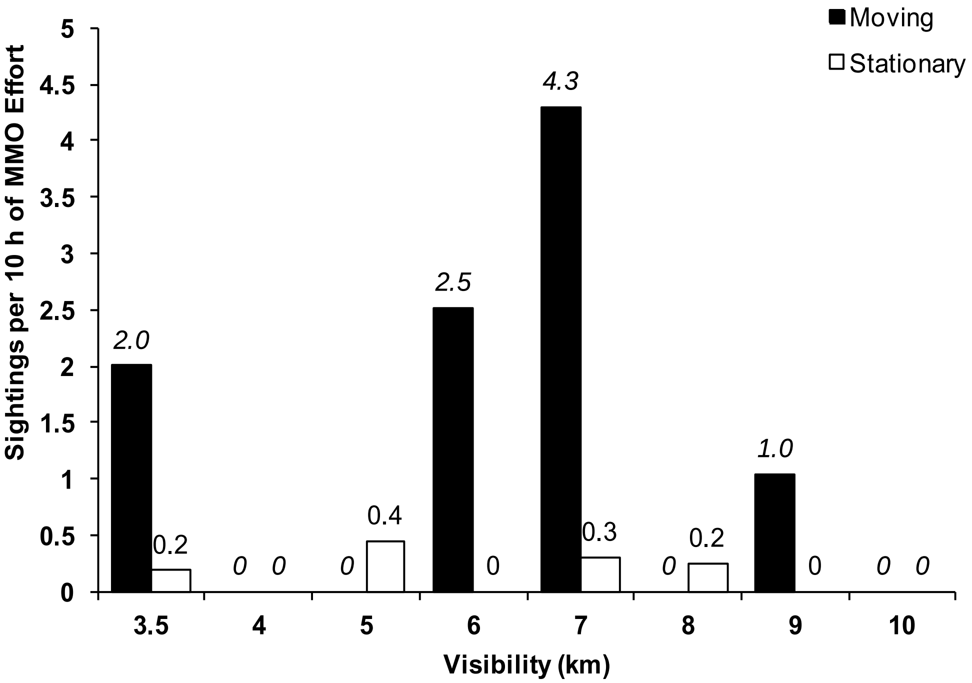

FIGURE 6.9. Seal sighting rates by visibility distance (km) from the *Synergy* during Statoil's geotechnical coring operations, 4 Sep – 27 Sep 2011. Italicized numbers indicate that the sighting rate may not be reliable due to a limited amount of observation effort having occurred within the category.

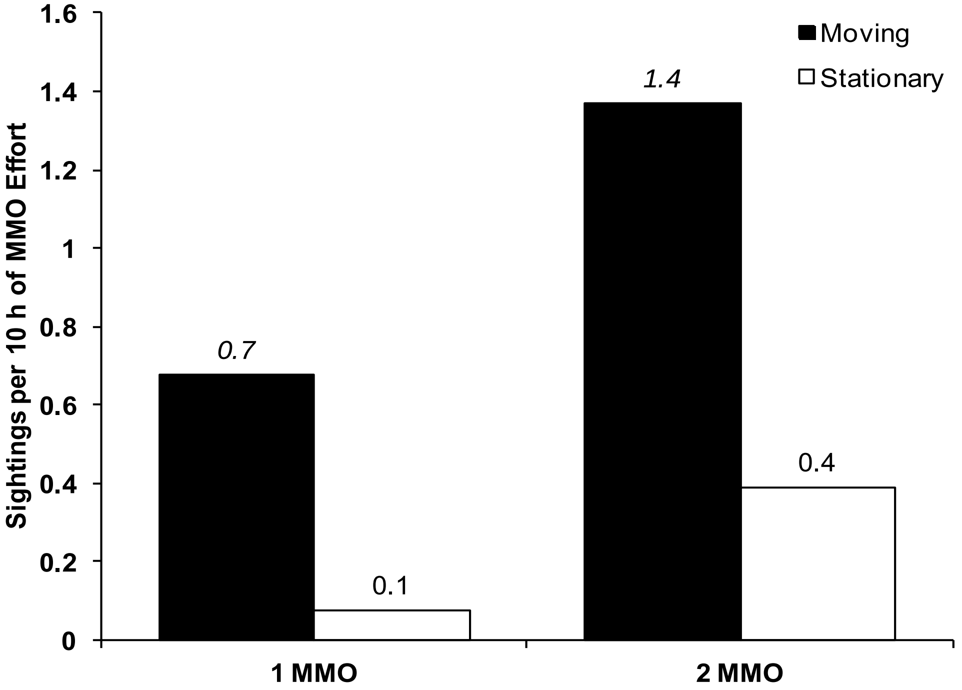

FIGURE 6.10. Seal sighting rates by number of MMOs on watch from the *Synergy* during Statoil's geotechnical coring operations, 4 Sep – 27 Sep 2011. Italicized numbers indicate that the sighting rate may not be reliable due to a limited amount of observation effort having occurred within the category.

Seal Sighting Rates by Vessel Activity – The seal sighting rate from the *Synergy* was highest during transits to and from Wainwright with similar sighting rates for stationary and stationary and coring periods (Fig. 6.9). Sighting rates during moving periods should be viewed with caution due to the limited amount of effort during transits as well as the overall low number of seal sightings.

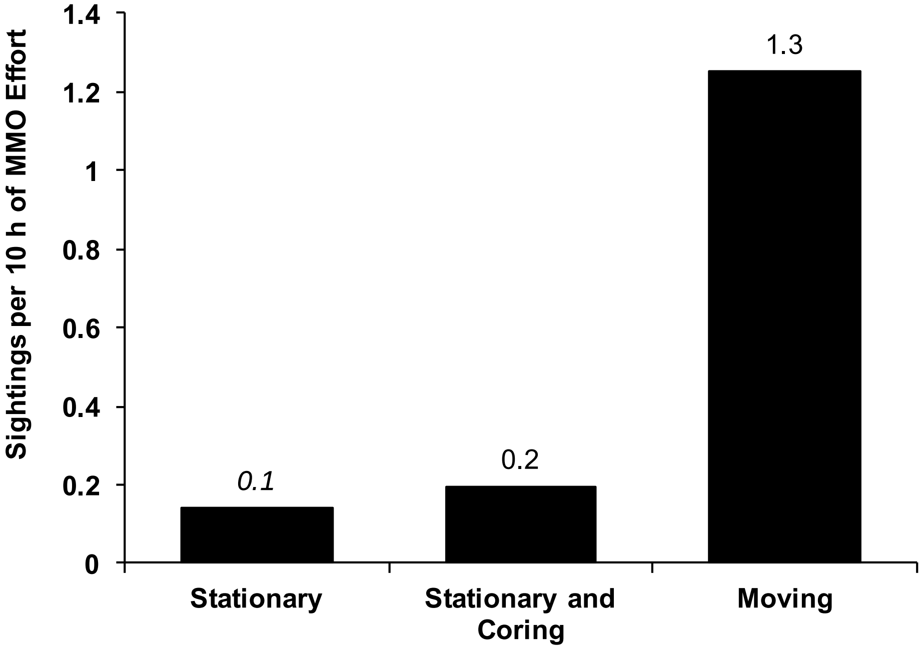

FIGURE 6.11. Seal sighting rates by vessel activity from the *Synergy* during Statoil's geotechnical coring operations, 4 Sep – 27 Sep 2011. Italicized numbers indicate that the sighting rate may not be reliable due to a limited amount of observation effort having occurred within the category.

Polar Bear Sightings

No polar bears were observed during Statoil's seismic survey.

Pacific Walrus Sightings

There were 20 Pacific walrus sightings of 49 individuals by MMOs on the *Synergy* (Table 6.3). The majority of these sightings (~85%) occurred while the vessel was in transit between the project area and Wainwright (Table 6.3).

TABLE 6.3. Number of Pacific Walrus sightings (number of individuals) from the *Synergy* during Statoil's geotechnical coring operations, 4 Sep – 27 Sep 2011.

Species	Moving	Stationary	Stationary and Coring	Sightings (Individuals)
Pacific Walruses	17 (45)	1 (1)	2 (3)	***20 (49)***

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 walruses (See Chapter 4 and Appendix C) and the sightings that occurred during those periods.

Pacific Walrus Sighting Rates by Beaufort Wind Force – Pacific walrus sighting rates from the *Synergy* were greatest during Bf four (Fig. 6.10). However, most walrus sightings occurred during transit with the majority of these occurring on 22 Sep, when a concentration of individuals was encountered between Wainwright and the project area. As a result, the number of different wind force conditions in which sightings walrus were encountered was limited.

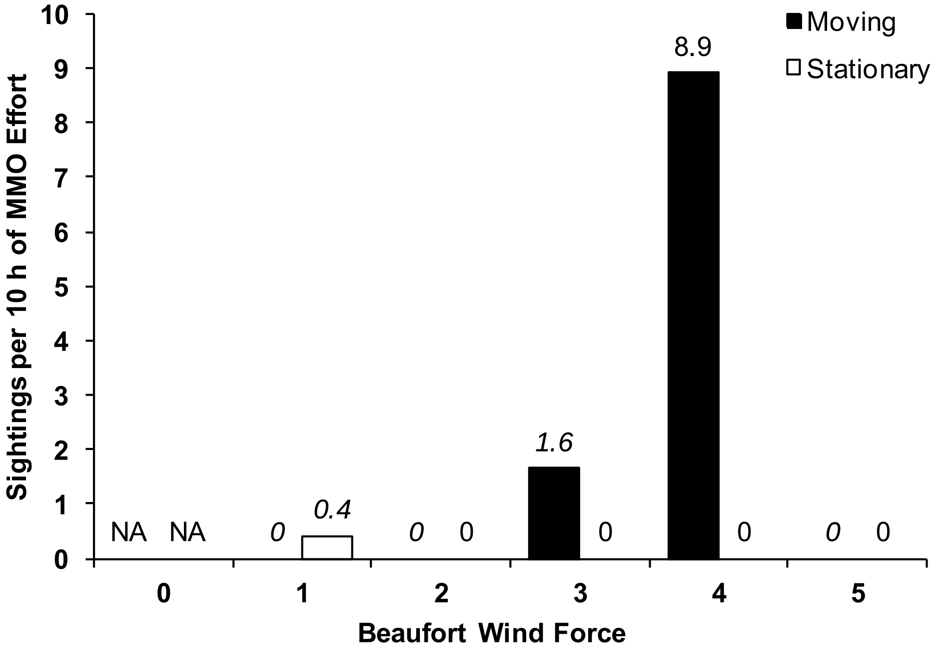

FIGURE 6.12. Walrus sighting rates by Beaufort wind force level from the *Synergy* during Statoil's geotechnical coring operations, 4 Sep – 27 Sep 2011. NA indicates that there was insufficient effort in the category to calculate a sighting rate. Italicized numbers indicate that the sighting rate may not be reliable due to a limited amount of observation effort having occurred within the category.

Pacific Walrus Sighting Rates by Visibility Distance – There was no clear trend in Pacific walrus sighting rates when compared with visibility distance. Since the majority of walrus sightings occurred when a concentration of individuals was encountered during transit from Wainwright on 22 Sep, rates of walrus sightings were more influenced by this encounter than by visibility distance.

Pacific Walrus Sighting Rates by Number of MMOs – Pacific Walrus sighting rates were greater with one MMO on watch than two MMOs on watch during both moving and stationary periods (Fig. 6.11). However, the amount of time the vessel was underway was limited and again, the majority of sightings occurred during one encounter with a concentration of individuals on 22 Sep, so the two sighting rates from moving periods should be viewed with caution.

Pacific Walrus Sighting Rates by Vessel Activity – The fact that the majority of walrus sightings occurred during transits to and from Wainwright is clearly shown in Fig. 6.12.

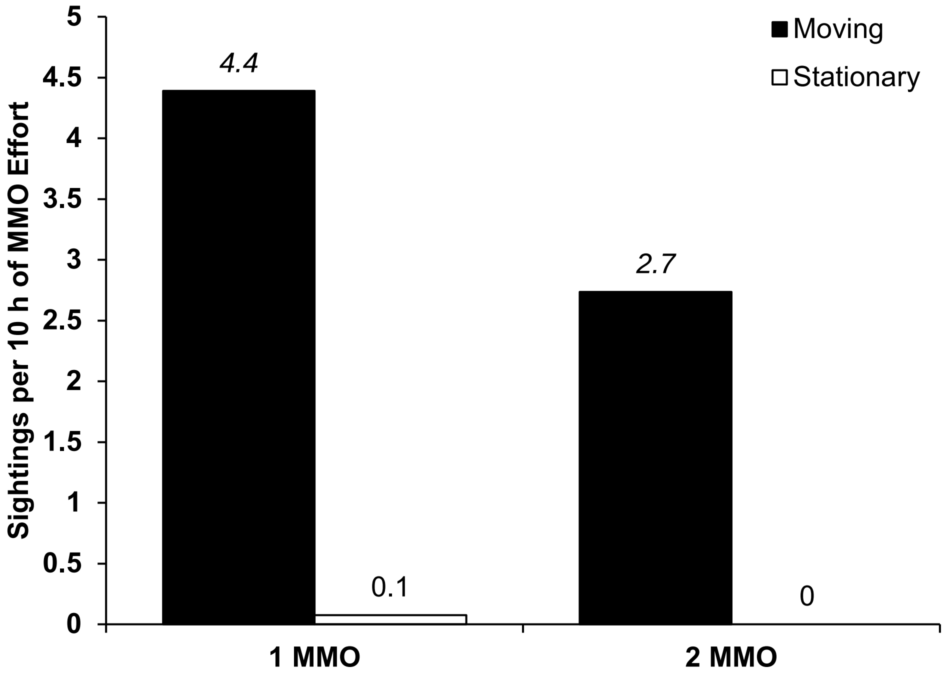

FIGURE 6.13. Walrus sighting rates by number of MMOs on watch from the *Synergy* during Statoil's geotechnical coring operations, 4 Sep – 27 Sep 2011. Italicized numbers indicate that the sighting rate may not be reliable due to a limited amount of observation effort having occurred within the category.

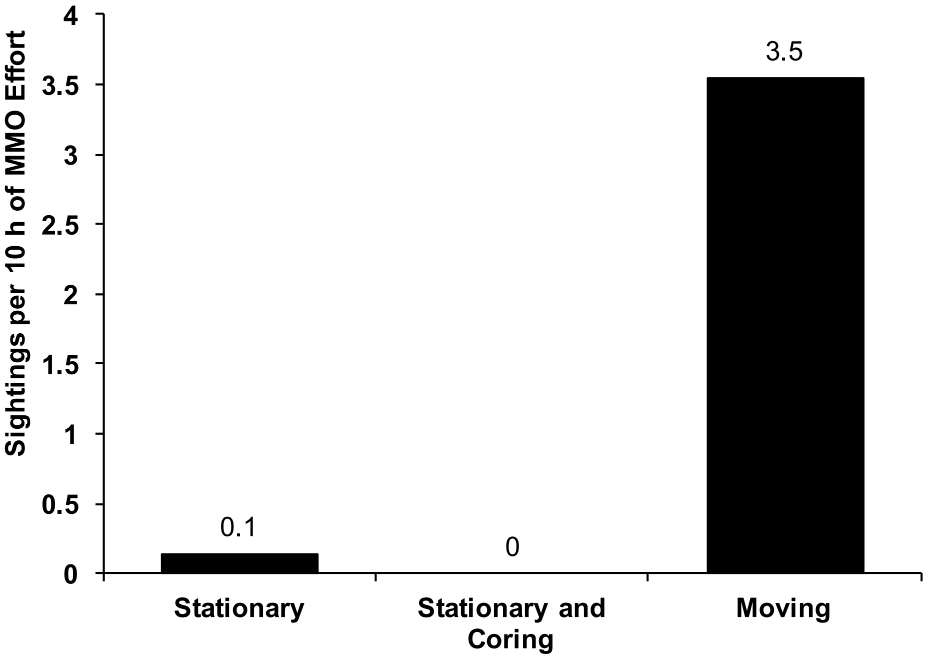

FIGURE 6.14. Walrus sighting rates by vessel activity from the *Synergy* during Statoil's geotechnical coring operations, 4 Sep – 27 Sep 2011.

Unidentified Marine Mammal Sightings

The *Synergy* had 14 unidentified sightings that were either too brief, too distant, or occurred during periods of low visibility to accurately identify to species. Details of each unidentified marine mammal sighting in the survey area are available in Appendix H. The following materials provide the likely species assignments for unidentified sightings based on comments written by the observer at the time of the sightings. Sightings with little or no additional diagnostic information recorded by the MMO remain classified here as unidentified sightings.

TABLE 6.4. Number of unidentified marine mammal sightings from the *Synergy* during Statoil's geotechnical coring operations, 4 Sep – 27 Sep 2011.

Species	Sightings (Individuals)
Unidentified Marine Mammals	
Unidentified Mysticete Whale	3 (4)
Unidentified Pinniped	5 (5)
Unidentified Seal	5 (5)
Total	***13 (14)***

Cetaceans – It is likely that 2 of the 3 unidentified mysticete whale sightings were gray whales, due to the shape and size of their blow as well as physical whale descriptions written by the MMO at the time of sighting. There was insufficient additional information written by the MMO to assign a likely species to the two remaining unidentified mysticete whale sightings.

Pinnipeds – Of the 10 unidentified pinnipeds and seals, 2 could be estimated to species using the descriptions provided at the time of the sighting. Details such as the size and color of the pinniped, the presence or absence of tusks, and the shape of the face led to the designation of one bearded seal and one Pacific walrus. Sufficient information was not present for assigning a likely species classification to the remaining eight sightings.

Distribution and Behavior of Marine Mammals

Cetaceans

Cetacean Initial Sighting Distance and Distribution

The comparison of initial sighting distances of cetaceans between different operations periods is usually made only with sightings that occurred during periods of effort that met the criteria for being able to reliably detect cetaceans (See Chapter 4 and Appendix C). Of the five sightings from the *Synergy*, only two sightings met those criteria and both occurred while the vessel was transiting to/from Wainwright. The small sample limited to only one operational category does not allow for meaningful comparison, however, the initial sightings distance and direction from the vessel of all sightings during both moving and stationary periods are depicted in Figures 6.15 and 6.17.

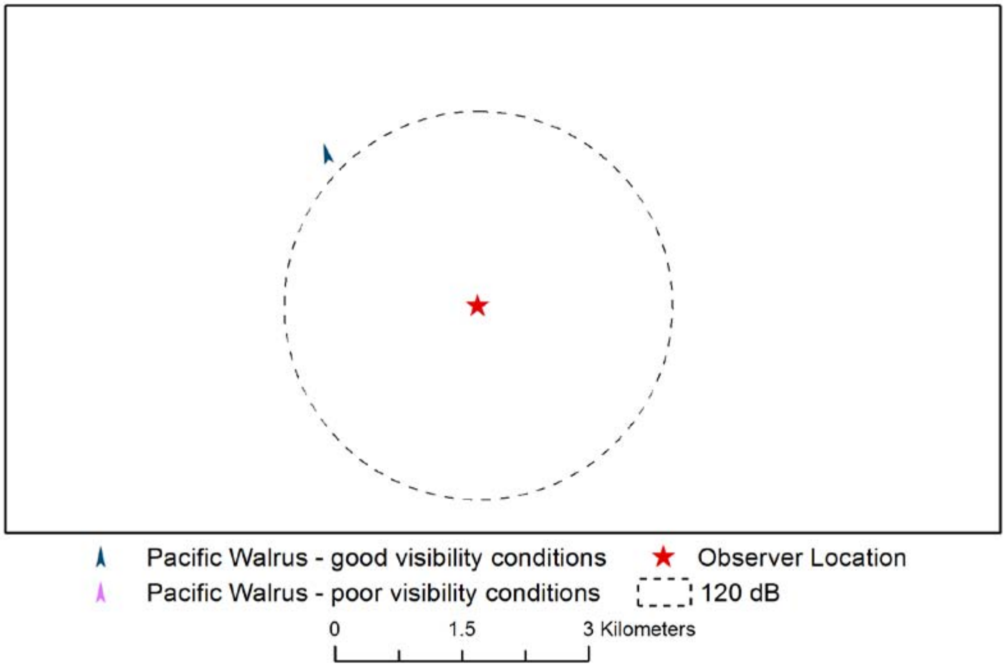

FIGURE 6.15. Distance and direction of initial cetacean sightings while the *Synergy* was stationary during Statoil's seismic survey, 4 Sep – 27 Sep 2011. Arrows indicate direction of animal movement.

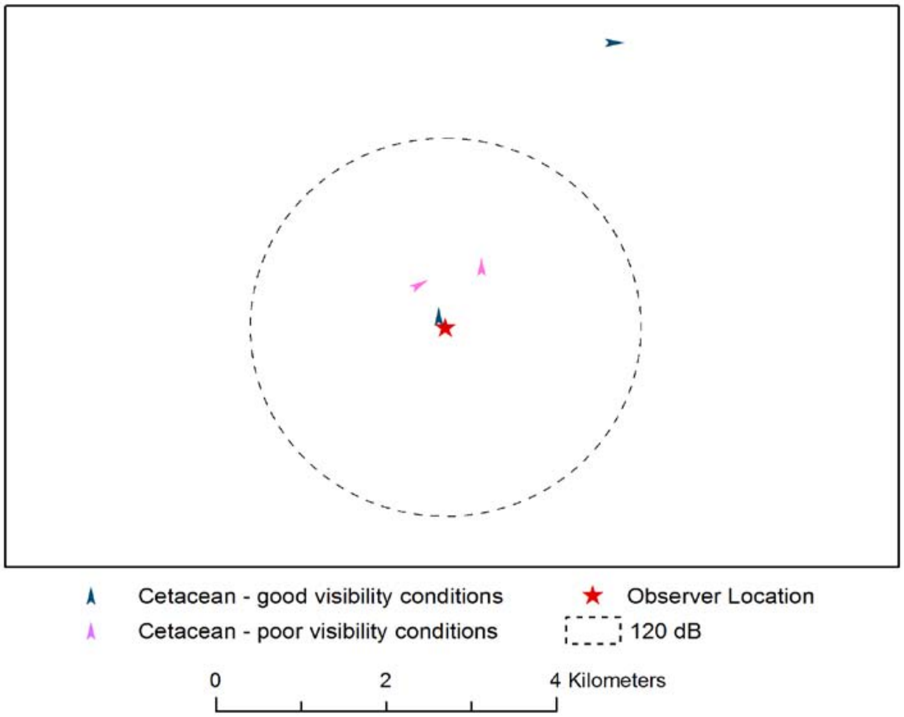

FIGURE 6.16. Distance and direction of initial cetacean sightings while the *Synergy* was moving during Statoil's seismic survey, 4 Sep – 27 Sep 2011. Arrows indicate direction of animal movement.

Cetacean Closest Point of Approach

Since only two cetacean sightings occurred during periods of effort that met the criteria for being able to reliably detect cetaceans, and both of those occurred while the vessel was moving, a meaningful comparison of the mean closest points of approach (CPAs) between vessel activity periods is not possible. The mean CPA of the two cetaceans observed in good visibility conditions during moving periods was 2072 m (2266 yd). Cetaceans were observed from the *Synergy* as close as 150 m (164 yd) and as far as 3993 m (3711 yd). The sighting with the 150 m (164 yd) CPA was of a pair of feeding gray whales that surfaced unexpectedly ahead of the vessel. In response, MMOs requested an immediate reduction in speed and ensured the whales were not in the path of the vessel.

Cetacean Movement

Of the five cetacean sightings on the *Synergy*, four occurred while the vessel was in transit to/from Wainwright. The animal(s) was either not moving or its movement was neutral relative to the vessel (swimming neither towards or away from the vessel) in three sightings while in the remaining sighting movement was unknown as only a single blow was observed. One cetacean sighting occurred while the *Synergy* was stationary but not coring and that animal was observed swimming away from the vessel.

Cetacean Initial Behavior

Of the five cetacean sightings on the *Synergy*, four occurred while the vessel was in transit to/from Wainwright. The observed initial behavior of three of these sightings was blow. Feeding was the observed initial behavior of the fourth sighting while in transit (as indicated by mud plumes observed in the immediate vicinity). One cetacean sighting occurred during stationary (non-coring) activity and the observed initial behavior was also blow. Blow is often the most frequently recorded initial behavior as it is a highly visible sighting cue and often the first and only indication of cetacean presence.

Cetacean Reaction Behavior

No cetaceans sighted from the *Synergy* exhibited an overt (or discernible) reaction to the vessel.

Seals

Seal Initial Sighting Distance and Distribution

The initial sighting distance of seals was calculated using only sightings that occurred during periods of effort that met the criteria for being able to reliably detect seals (See Chapter 4 and Appendix C). Due to the low sample size of ten seal sightings that met these criteria, any comparisons are limited in meaning. For example, the low mean initial sighting distance during stationary non-coring activities compared to other activities was the result of only a single seal sighting (Table 6.5).

TABLE 6.5. Comparison of mean seal initial sighting distances by vessel activity from the *Synergy* during Statoil's geotechnical coring operations, 4 Sep – 27 Sep 2011. The overall mean includes initial sighting distances from all three vessel activities.

Vessel Activity	Mean Initial Sighting Distance (m)	s.d.	Range (m)	*n*
Stationary	20	--	--	***1***
Stationary and Coring	125	152	30-300	***3***
Moving	98	105	20-300	***6***
Overall	***99***	***110***	***20-300***	***10***

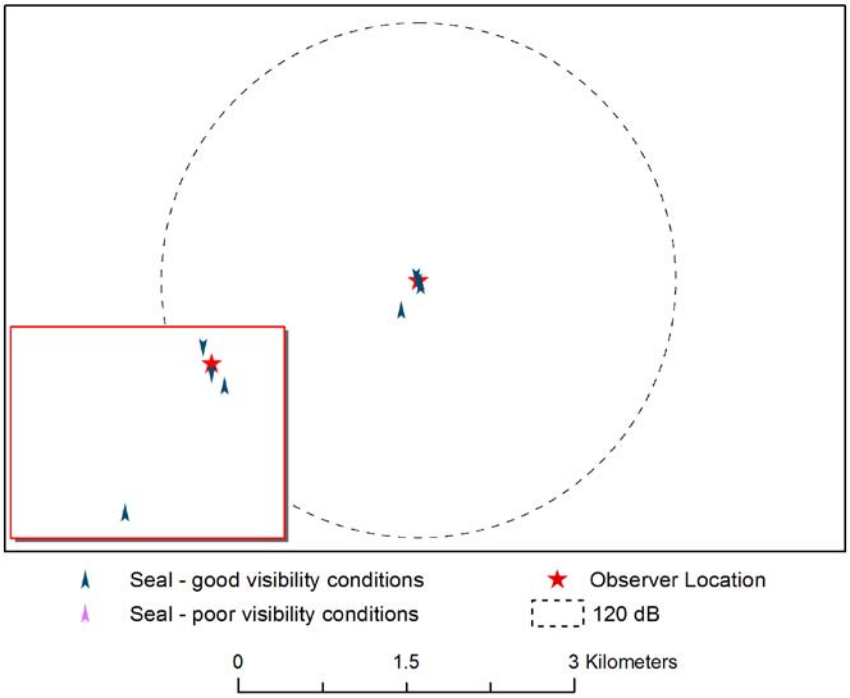

FIGURE 6.17. Distance and direction of initial seal sightings from the *Synergy* while it was stationary during Statoil's seismic survey, 4 Sep – 27 Sep 2011. Arrows indicate direction of animal movement.

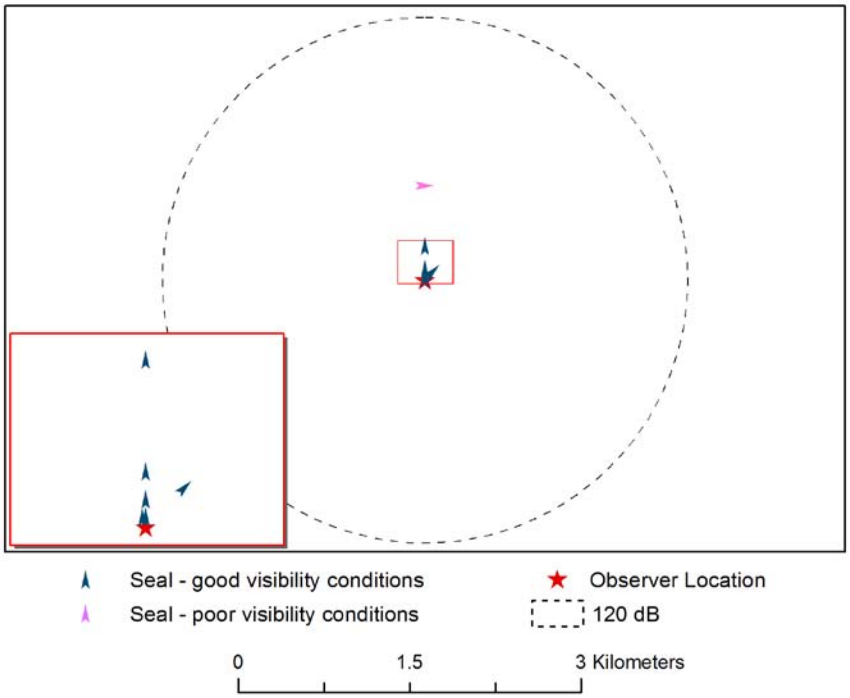

FIGURE 6.18. Distance and direction of initial seal sightings from the *Synergy* while it was moving during Statoil's seismic survey, 4 Sep – 27 Sep 2011. Arrows indicate direction of animal movement.

Seal Closest Point of Approach

The mean closest points of approach of seals were 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 C). The mean closest point of approach (CPA) for seals observed from the *Synergy* was lower during stationary periods when coring was not occurring than when coring was occurring. The sample size of sightings during both periods was very limited and this difference was the result of only a single sighting with a CPA of 20 m during a stationary period without coring (Table 6.6).

TABLE 6.6. Comparison of mean seal CPA distances by vessel activity from the *Synergy* during Statoil's geotechnical coring operations, 4 Sep – 27 Sep 2011. The overall mean includes CPA distances from all three vessel activities.

Vessel Activity	Mean CPA[a] (m)	s.d.	Range (m)	*n*
Stationary	20	--	--	***1***
Stationary and Coring	120	156	30-300	***3***
Moving	98	105	20-300	***6***
Overall	***97***	***111***	***20-300***	***10***

---

[a] CPA=Closest Point of Approach. For *Synergy* this value is the marine mammal's closest point of approach to the MMO position on the vessel.

Seal Movement

Of the 12 seal sightings observed from the *Synergy*, eight occurred while the vessel was moving in transit to/from Wainwright. Of these eight seals, movement relative to the vessel was unable to be determined in six cases, while neutral movement and swimming away were exhibited in the remaining two sightings (Table 6.7). While stationary in dynamic positioning mode one seal was observed swimming towards and one away from the vessel (Table 6.7). The other two sightings occurred during stationary coring operations and the movements were either none or unable to be determined (Table 6.7).

Seal Initial Behavior

The initial behaviors of seals observed from the *Synergy* varied considerably (Table 6.8). Behaviors such as looking and thrash, which indicate an awareness of the vessel, only occurred while the *Synergy* was moving (Table 6.8).

Seal Reaction Behavior

Seals observed from the *Synergy* while it was underway were most often recorded as splashing, looking at the vessel, and changing direction (Table 6.9). Seals observed from the *Synergy* while stationary in either dynamic positioning mode or during coring operations had no apparent reaction to the vessel (Table 6.9).

TABLE 6.7. Number of seal sightings within categories of movement relative to vessels by vessel activity from the *Synergy* during Statoil's geotechnical coring operations, 4 Sep – 27 Sep 2011.

	Movement Relative to Vessel					
Vessel Activity	**Swim Towards**	**Swim Away**	**Neutral**	**None**	**Unknown**	***Totals***
Stationary	1	1	0	0	0	***2***
Stationary and Coring	0	0	0	1	1	***2***
Moving	0	1	1	0	6	***8***
Overall	***1***	***2***	***1***	***1***	7	***12***

TABLE 6.8. Comparison of seal behaviors by vessel activity from the *Synergy* during Statoil's geotechnical coring operations, 4 Sep – 27 Sep 2011.

	Initial Behavior						
Vessel Activity	**Looking**	**Surface Active**	**Swim**	**Breach**	**Thrash**	**Unknown**	***Totals***
Stationary	0	1	0	1	0	0	***2***
Stationary and Coring	0	0	1	0	0	1	***2***
Moving	3	1	2	0	2	0	***8***
Overall	***3***	***2***	***3***	***1***	***2***	***1***	***12***

TABLE 6.9. Comparison of seal reactions to the vessel by vessel activity from the *Synergy* during Statoil's geotechnical coring operations, 4 Sep – 27 Sep 2011.

	Reaction					
Vessel Activity	**Splash**	**Increase in Speed**	**Change in Direction**	**Look at Vessel**	**None**	***Totals***
Stationary	0	0	0	0	2	***2***
Stationary and Coring	0	0	0	0	2	***2***
Moving	2	1	2	2	1	***8***
Overall	***2***	***1***	***2***	***2***	***5***	***12***

Pacific Walruses

Pacific Walrus Initial Sighting Distance and Distribution

The initial sighting distance of walruses was calculated using only sightings that occurred during periods of effort that met the criteria for being able to reliably detect walruses (See Chapter 4 and Appendix C). The majority of walrus sightings occurred while the vessel was moving during transits to/from Wainwright. There was only a single sighting during stationary (non-coring) activity that met the data analysis criteria, so meaningful comparison across activities is limited.

TABLE 6.10. Comparison of mean walrus initial sighting distances by vessel activity from the *Synergy* during Statoil's geotechnical coring operations, 4 Sep – 27 Sep 2011. The overall mean includes sighting distances from all three vessel activities.

Vessel Activity	**Mean Initial Sighting Distance (m)**	**s.d.**	**Range (m)**	***n***
Stationary	50	--	--	***1***
Stationary and Coring	0	--	--	***0***
Moving	116	69	15-250	***17***
Overall	***113***	***68***	***15-250***	***18***

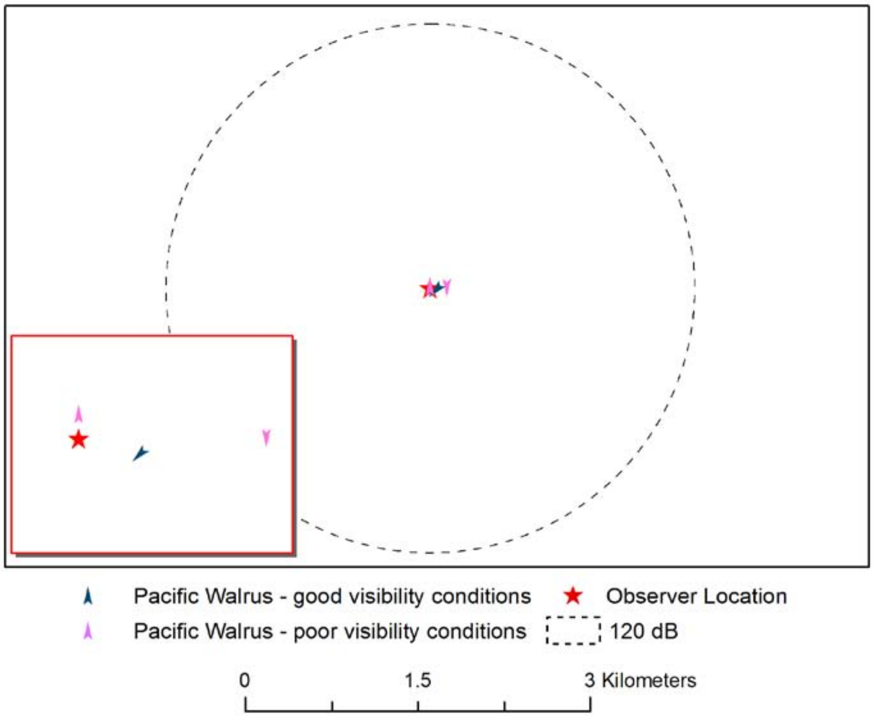

FIGURE 6.19. Distance and direction of initial walrus sightings from the *Synergy* while it was stationary during Statoil's seismic survey, 4 Sep – 27 Sep 2011. Arrows indicate direction of animal movement.

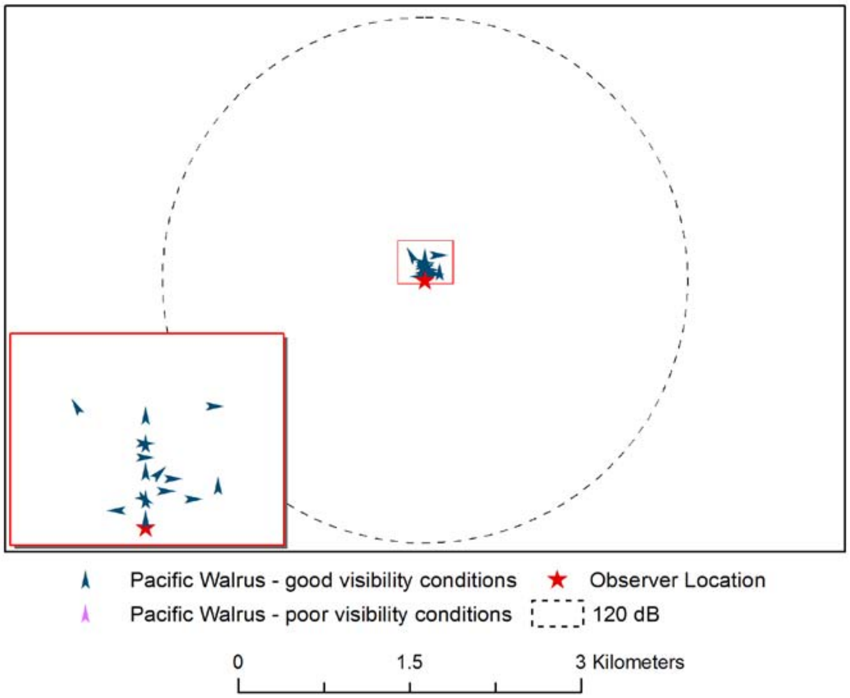

FIGURE 6.20. Distance and direction of initial walrus sightings from the *Synergy* while it was moving during Statoil's seismic survey, 4 Sep – 27 Sep 2011. Arrows indicate direction of animal movement.

Pacific Walrus Closest Point of Approach

The mean closest points of approach of Pacific walruses were calculated using only sightings that occurred during periods of effort that met the criteria for being able to reliably detect Pacific walruses (See Chapter 4 and Appendix C). Most walrus sightings that met these criteria occurred while the vessel was underway in transit to and from Wainwright (Table 6.11). Walruses were observed from the vessel as close as 15 m (16 yd) and as far as 250 m (273 yd) while it was underway. There was only one sighting of a walrus that met the data analysis criteria while the *Synergy* was stationary and its CPA was 50 m. However, there was a sighting of a walrus that did not meet the analysis criteria which involved a walrus approaching the vessel during stationary coring activities. This individual was presumably seeking to haul out on the vessel, and approached and physically contacted the hull of the *Synergy* several times throughout the ~14 hour duration of this sighting (See Mitigation Actions for greater detail).

Pacific Walrus Movement

Movements that were neutral relative to the vessel or no movement were the only two recorded movements of walruses observed from the *Synergy* while it was stationary (Table 6.12). The movements of walruses observed while the vessel was underway included swim away, neutral, and none.

TABLE 6.11. Comparison of mean walrus CPA distances by vessel activity from the *Synergy* during Statoil's geotechnical coring operations, 4 Sep – 27 Sep 2011. The overall mean includes CPA distances from all three vessel activities.

Vessel Activity	Mean CPA[a] (m)	s.d.	Range (m)	*n*
Stationary	50	--	--	***1***
Stationary and Coring	--	--	--	**--**
Moving	106	69	15-250	***17***
Overall	***103***	***68***	***15-250***	***18***

[a] CPA=Closest Point of Approach. For Synergy this value is the marine mammal's closest point of approach to the MMO position on the vessel.

TABLE 6.12. Number of Pacific walrus sightings by movement relative to vessels by vessel activity from the *Synergy* during Statoil's geotechnical coring operations, 4 Sep – 27 Sep 2011.

	Movement Relative to Vessel			
Vessel Activity	**Swim Away**	**Neutral**	**None**	***Totals***
Stationary	0	1	0	***1***
Stationary and Coring	0	1	1	***2***
Moving	4	6	3	***17***
Overall	***4***	***8***	***4***	***20***

Pacific Walrus Initial Behavior

Of the 20 walrus sightings observed from the *Synergy*, 17 of them occurred during transit to/from Wainwright. Of those 17 sightings, the initial behavior was most often looking at the vessel (13 sightings). Swimming was recorded as the initial behavior for three sightings and one "other" behavior (a female grasping her calf in her front flippers) was observed. The initial behavior of the two sightings recorded during stationary coring operations was swim. One of these animals remained around the vessel for ~14 h and appeared to be in distress and/or haul out on the vessel. Subsequent behaviors exhibited by that animal while it was near the vessel included approaching the vessel, diving around the vessel, looking at the vessel and crew, and occasionally touching the vessel. The one walrus sighted during stationary non-coring activities had an observed initial behavior of looking at the vessel.

Pacific Walrus Reaction Behavior

Walruses observed from the *Synergy* most frequently reacted to the vessel by looking at it, both while the vessel was moving (71%) and while it was stationary (67%; Table 6.13). The second-most commonly observed reaction was a change in direction (Table 6.13). Other reactions to the *Synergy* while it was underway include splash and increase in speed. The walrus that remained around the vessel for ~14 h clearly reacted to the vessel by looking at it, swimming/diving around the vessel, and touching the vessel in what may have been attempts to haul out on the vessel.

TABLE 6.13. Comparison of Pacific walrus reactions to the vessel by vessel activity from the *Synergy* during Statoil's geotechnical coring operations, 4 Sep – 27 Sep 2011.

	Reaction				
Vessel Activity	**Splash**	**Increase in Speed**	**Change in Direction**	**Look at Vessel**	***Totals***
Stationary	0	0	1	0	***1***
Stationary and Coring	0	0	0	2	***2***
Moving	1	1	3	12	***17***
Overall	***1***	***1***	***4***	***14***	***20***

Mitigation Measures Implemented

Safety and Disturbance Radii

Prior to completion of the sound source verification measurements, MMOs on the Statoil vessels used the modeled safety radii presented in Statoil's 2011 IHA application and outline in the IHA issued by NMFS (NMFS 2011) for mitigation purposes. Once Statoil's site specific sound source verification (SSV) was completed on 9 Sep 2011, the results were reported (Warner et. al. 2011) on 15 Sep 2011, the distances shown in Table 4.2 were implemented for mitigation purposes throughout the duration of the survey.

Mitigation Actions

A total of three mitigation actions were requested and implemented on the *Synergy* during Statoil's 2011 geotechnical survey in the Chukchi Sea. Two were related to general vessel operations during transits and involved requests to reduce vessel speed to mitigate approaches to cetaceans and walrus observed ahead of the vessel. The third was a precautionary mitigation request for heighten monitoring of the vessel's moon pool. This was implemented during geotechnical coring operations due to the prolonged presence of a walrus in the waters around the *Synergy*.

The two mitigation requests related to general vessel operations were implemented during transits to and from Wainwright. In one instance, on 9 Sep (sightings ID SYN201125, Appendix G), a pair of gray whales surfaced 150 m ahead and starboard of the *Synergy* (a third single gray whale was sighted near them at approximately 500 m). An immediate reduction in speed was requested and implemented while moving past the whales to reduce the potential for a ship strike. The gray whales appeared to be feeding and no reactions were observed as the vessel passed by at 9.5 knots. The *Synergy* resumed its original transit speed of 10.5 knots after no other marine mammals were detected ahead of vessel for approximately fifteen minutes.

During transit from Wainwright to the Statoil leases on 22 Sep, the *Synergy* passed through an area with a higher concentration of Pacific walrus than observed elsewhere along the route. The walrus appeared in small, tight groups typically consisting of adult females with young of the year and/or juveniles. The walruses were surfacing ahead of the *Synergy* and after several groups surfaced simultaneously within ~100 m of the vessel, a reduction in speed from 11 kts down to 9 kts was requested and implemented as it became apparent that more walrus encounters were likely. Typical reactions were surfacing and looking at the oncoming vessel as it passed by. Often the walrus groups ahead of the *Synergy* would delay changing direction and increasing speed to flee the vessel until they were within 50-100 m of the vessel. In one instance, a female with young calf surfaced ~30 m from the vessel and did not attempt to dive away from the oncoming vessel until it was within ~15 m, when it proceeded to grasp the calf in its fore flippers and pushed it away as the vessel passed by. The *Synergy's* speed was maintained at or below 9 knots until reaching the Statoil survey area and assuming a stationary position. No walruses were sighted on arrival at the survey area.

One request for increased monitoring of the moon pool was implemented as a precautionary measure during an unusual walrus observation during coring operations. On 10 Sep (sightings ID STASYN20114, Appendix G), a walrus approached the *Synergy,* appearing distressed and behaving as though it were seeking to haul out. The walrus circled the vessel continuously in close proximity ~10–60 m (touching the vessel several times possibly in an attempt to haul out) for approximately 14 hours. This behavior suggested an increased likelihood the walrus may attempt entry into the moon pool (the only location where it was possible for the walrus to haul out) during coring operations. As a precautionary measure, vessel officers and deck crews were informed of the walrus and requested to assist MMOs in continually monitoring the whereabouts of walrus. A procedure for stopping the drill string was established in the event the walrus did enter the moon pool during coring operations. At the end of coring operations the moon pool was opened and visually inspected by the drilling crew to ensure the walrus was not present in this enclosed space prior to retrieval of the seabed frame from the water. This was to eliminate the possibility that the walrus could be injured when the seabed frame entered the moon pool during retrieval. MMOs continuously monitored the location and activities of the walrus to rule out moon pool entry during coring operations (which is covered and cannot be monitored during coring activities due to safety/location). In addition, the USFWS was notified of the continued presence of the walrus around the vessel. The walrus remained visible in the water around the hull outside of the *Synergy* for the duration of this borehole coring. After completing coring and retrieval of the drill string and seabed frame, the *Synergy* moved 70 m to the next site in dynamic positioning mode. The walrus did not follow the vessel to this next location and it was not observed again.

Estimated Number of Marine Mammals Present and Potentially Affected

It is often difficult to obtain meaningful estimates of "take by harassment" 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 (RSL) reaches a specific criterion such as 190 dB, 180 dB, or 160 dB, or 120 dB re 1 µPa (rms) is variable. The RSL 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 (seal and Pacific walrus) and cetacean densities obtained during this study. The actual number of individuals exposed to, and potentially impacted by, seismic survey or coring 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.

Disturbance and Safety Criteria

Table 4.2 summarizes the estimated RSLs at various distances from the *Synergy* while it was stationary using dynamic positioning thrusters and while it was stationary and also conducting coring operations. The NMFS required that distances to RSLs of 180 dB and 190 dB (rms) be used to implement mitigation measures for cetaceans and seals respectively. The USFWS required that distances to RSLs of 180 dB and 190 dB (rms) be used to implement mitigation measures for Pacific walruses and polar bears, respectively. Measurements of sounds produced by the vessel while stationary, with and without ongoing coring operations, indicated that sound levels at or above these thresholds were not generated (see Chapter 3 of this report for sound measurement details). Both agencies assume that disturbance to marine mammals from continuous sounds generated by the vessel while conducting coring operations may occur at RSLs ≥120 dB (rms).

Estimates from Direct Observations

All sightings data were included in the following exposure estimates based on direct observations, regardless of whether they met the data-analysis criteria described in Chapter 4. The number of animals actually sighted by observers within the various sound level distances during coring activities provides a minimum estimate of the number potentially affected by the continuous sounds from the vessel. Some animals may have 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 vessels position. During daylight, animals are missed if they are below the surface when the ship is nearby. Other animals, even if they surface near the vessel, are missed because of limited visibility (e.g. fog), glare, or other factors limiting sightability. Furthermore, marine mammals could not be seen effectively during periods of darkness, which increased as the operation progressed into late Sep. Nighttime observations were not required, however, MMOs aboard the *Synergy* were available throughout the night and conducted occasional monitoring using night vision devices in order to test and assess their effectiveness under various conditions.

Animals may also have avoided the area near the *Synergy* while it was coring (see Richardson et al. 1995). Within the measured ≥120 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 coring operations.

Cetaceans Potentially Exposed to Received Sound Levels ≥120 dB re 1 μPa (rms)

Only one cetacean was observed from the *Synergy* while it was stationary. This sighting occurred while the vessel was in dynamic positioning mode but it was not coring at the time. The closest point of approach was 2549 m (2788 yd).

Seals Potentially Exposed to Received Sound Level ≥120 dB re 1 μPa (rms)

Four seals (four different sightings) were observed from the *Synergy* while it was stationary. Three of these animals were present while coring activities were taking place. The closest point of approach for two of the animals was 30 m (33 yd), and the CPA of the third animal was 300 m (328 yd). The ≥120 dB disturbance radius for the *Synergy* in dynamic positioning mode while coring was 1775 m (1941 yd, Table 4.2) so all four animals were likely exposed to received levels of continuous sounds ≥120 dB (rms).

Pacific Walruses Potentially Exposed to Received Sound Level ≥120 dB re 1 μPa (rms)

Four Pacific walrus (three sightings) were observed from the *Synergy* while it was stationary; of these, three individuals (two sightings) occurred while coring was taking place. The closest points of approach of these two sightings were 10 m (11 yd) and 100 m (109 yd). The ≥120 dB safety radius for the *Synergy* in dynamic positioning mode while coring was 1775 m (1941 yd, Table 4.2) so these animals occurred well within that distance.

Estimates Extrapolated from Density

The number 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 detected 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 during those two periods. The estimated densities of marine mammals were then multiplied by the area of water ensonified (exposed to continuous sounds during coring operations) to estimate the number of individual marine mammals exposed to continuous received sound levels (RSL) ≥120 dB (rms). The three to four coring locations at each of the five potential well sites on Statoil's leases were spaced ~70 m apart which resulted in substantial overlap of the measured ≥120 dB distance (2.3 km) from each coring location at each well site. The ratio of the total area exposed to coring sounds including multiple counts of areas exposed more than once to the area of water exposed excluding multiple counts was 3.2. This represents the average number of exposures per individual marine mammal present near the coring vessel if the individual had remained there throughout the activities at one of the potential well site.

Marine mammal densities were based on data collected from both the *Duke* and *Synergy* during Statoil's site surveys and geotechnical coring operations in the Chukchi Sea. Because there were so few sightings from the *Synergy* while it was stationary and coring, the densities calculated and used in the exposure estimates below were based only on observer effort and sightings data while the vessels were moving. For analysis of periods with and without coring sounds being introduced to the water, the densities from seismic and non-seismic periods were used due to the limited number of sightings that occurred while the *Synergy* was stationary with or without ongoing coring operations. The density estimates for the Statoil survey area were calculated separately by season, summer (Aug) and fall (Sep) for consistency with the NMFS IHA application take estimates, but coring operations only occurred in Sep and those densities are shown in Table 6.14. The area of water exposed to various sound levels by the coring operations are shown in Table 6.15. The methodology used to estimate the areas exposed to RSLs ≥120, 160, 170, 180 and 190 dB (rms) was described in Chapter 4 and in more detail in Appendix C.

The following estimates based on density calculations assume that all mammals present were well below the surface where they were exposed to RSLs at various distances as reported in Chapter 3 and summarized in Table 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 marine mammals may have stayed away from the *Synergy* as it was coring in an avoidance response to the coring sounds.

Cetaceans

Table 6.16 shows the estimated numbers of cetacean that may have been exposed to coring sounds at received levels ≥120 dB (rms) based on the density estimates in Table 6.14 and the ensonified areas in Table 6.15. The number of cetaceans potentially exposed to continuous sounds ≥120 dB (rms) is substantially lower than that calculated in the IHA application due to the shorter than predicted distance of the 120 dB (rms) sound isopleth and the fact that cores were collected at fewer sites than initially proposed.

TABLE 6.14. Fall (Sep) densities of marine mammals in the Alaskan Chukchi Sea observed during Statoil's site survey and geotechnical coring, 6 Aug – 27 Sep 2011. Densities are corrected for *f*(0) and *g*(0) biases (see Appendix C).

	No. individuals / km^2					
	Seismic			Non-seismic		
Species	**Density**	**LCL**	**UPC**	**Density**	**LCL**	**UPC**
Cetaceans						
Gray whale	0.000	--	--	0.001	0.000	0.013
Unid. mysticete whale	0.000	--	--	0.001	0.000	0.003
Total Cetaceans	***0.000***	***--***	***--***	***0.002***	***0.001***	***0.013***
Seals						
Ringed Seal	0.022	0.006	0.074	0.005	0.000	0.062
Spotted Seal	0.000	--	--	0.000		
Bearded Seal	0.111	0.031	0.507	0.014	0.001	0.078
Unid. Seal	0.014	0.001	0.169	0.007	0.000	0.069
Unid. Pinniped	0.013	0.001	0.125	0.007	0.001	0.072
Total Seals	***0.160***	***0.058***	***0.448***	***0.033***	***0.005***	***0.113***
Pacific walrus	0.035	0.009	0.164	0.059	0.012	0.259

TABLE 6.15. Estimated areas (km^2) ensonified to various sound levels during Statoil's geotechnical coring activities, 6 Aug – 23 Sep 2011.

		Level of ensonification in dB re 1 µPa (rms)				
	Area (km^2)	**190**	**180**	**170**	**160**	**120**
Fall	Including Overlap Area	0	0	16	86	317
	Excluding Overlap Area	0	0	5	27	100

Seals

The total number of seals estimated to have been exposed to continuous sounds ≥120 dB (rms) is 17. This may have included 12 bearded seals and 3 ringed seals. Since not all pinnipeds could be identified to species by the observers, the density based estimates also include 4 individual pinnipeds of unknown species.

Pacific walruses

Density based calculations estimate that ~6 individual walruses may have been exposed to continuous sounds with RSLs ≥120 dB (rms) during the coring activities (Table 6.16).

TABLE 6.16. Estimated numbers of individual marine mammals exposed to continuous sounds from coring activities ≥120 dB (rms) based on densities observed during seismic and non-seismic periods at received levels of during summer (Aug) of Statoil's 2011 site survey, 6 Aug – 23 Sep 2011. All fractional values in the table have been rounded up to the nearest whole number. The totals for cetaceans and seals were calculated on the sum of the densities within that group, not the sum of the rounded estimates for each species.

	Estimated No. Individuals						Requested Take	
	Seismic Densities			Non-seismic Densities				
Species	**Mean**	**LCL**	**UCL**	**Mean**	**LCL**	**UCL**	**Mean**	**Max**
Cetaceans								
Gray whale	0	--	--	1	1	2	26	51
Unid. mysticete whale	0	--	--	1	1	1	--	--
Total Cetaceans	***0***	***--***	***--***	***1***	***1***	***2***	45	90
Seals								
Ringed Seal	3	1	8	1	1	7	467	774
Spotted Seal	0	--	--	0	--	--	9	15
Bearded Seal	12	4	51	2	1	8	16	30
Unid. Seal	2	1	17	1	1	7	--	--
Unid. Pinniped	2	1	13	1	1	8	--	--
Total Seals	***17***	***6***	***45***	***4***	***1***	***12***	493	823
Pacific walrus	4	1	17	6	2	26	--	--

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7. SUMMARY OF MARINE MAMMAL MONITORING RESULTS[1]

Vessel Summary

Observer Effort

MMOs aboard the *Duke* were on watch for a total of ~8724 km (5421 mi; 1035 h). MMOs aboard the *Synergy* were on watch for a total of ~1094 km (680 mi; 55 h) while moving and ~277 hours while stationary. On the *Duke,* at least one observer was on watch during 100% (~3842 km; 2387 mi; 463 h) of daylight seismic operations and at least one observer was on watch during 100% (~1120 km; 696 mi; 133 h) of nighttime seismic operations. On the *Synergy,* at least one observer was on watch during 100% (182 h) of daylight coring operations and at least one observer was on watch during 100% (6 h) of nighttime coring operations. Of the total observation effort for both vessels, ~6% (84 h) occurred during darkness.

TABLE 7.1. Observer effort by vessel activity from the *Duke* and the *Synergy* during Statoil's seismic survey and geotechnical coring operations in the Chukchi Sea, 6 Aug – 27 Sep 2011.

Effort	***Duke***	***Synergy***
Transit (km)	3762	1846
Seismic (km)	4962	--
Stationary (h)	--	556
Coring (h)	--	189

Marine Mammal Sightings

Most marine mammal sightings were made when Beaufort wind force (Bf) conditions were low (Fig. 7.1). However, not all periods of low Bf resulted in high levels of sightings possibly due to other environmental variables including location and visibility distance. Generally, the highest number of sightings corresponded with daily average Bf conditions at or below 3. (Fig. 7.1).

Cetacean Sightings

Over the entire season, 16 sightings of 43 mysticete whales were observed in the northeastern Chukchi Sea. Approximately 68% of these sightings were observed by MMOs on the *Duke*. The majority of these sightings from both vessels (~63%) occurred during transit to and from Wainwright.

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[1] By Kris Hartin, Lauren Bisson, Sarah Case (LGL Alaska Research Associates, Inc.)

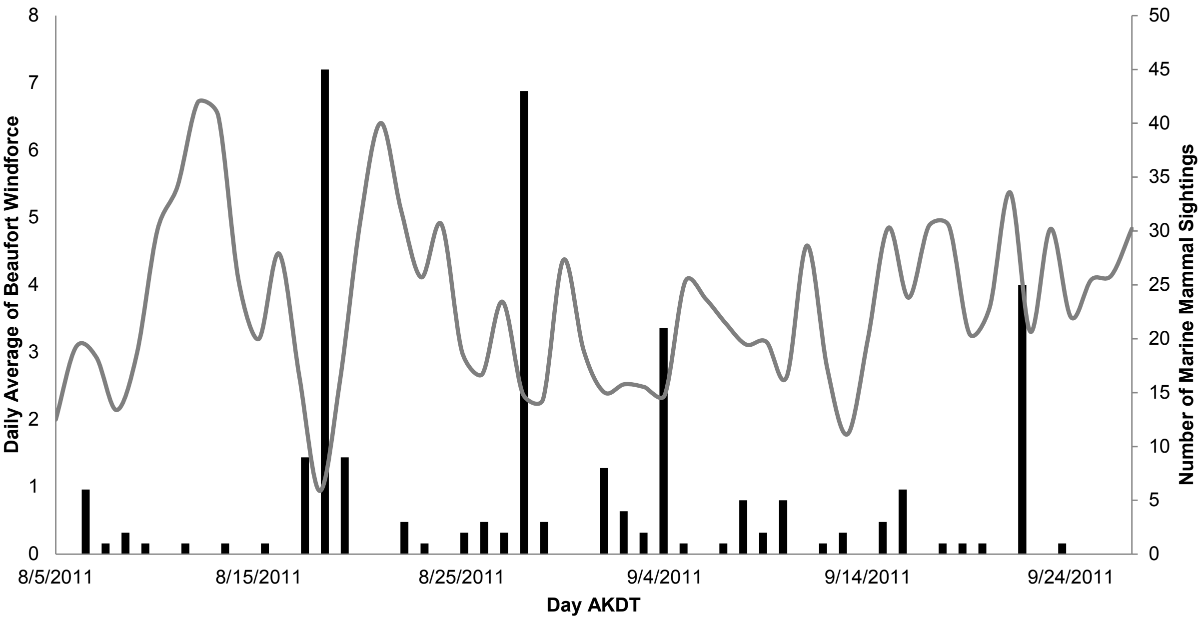

FIGURE 7.1. Marine mammal sightings during daily average Beaufort wind force conditions during Statoil's seismic survey and geotechnical coring operations in the Chukchi Sea, 6 Aug – 27 Sep 2011.

TABLE 7.2. Number of cetacean sightings (number of individuals) from the *Duke* and the *Synergy* during Statoil's seismic survey and geotechnical coring operations in the Chukchi Sea, 6 Aug – 27 Sep 2011.

Species	***Duke***	***Synergy***	***Total***
Cetaceans			
Gray Whale	6 (29)	2 (4)	**8 (33)**
Unidentified Mysticete Whale	5 (6)	3 (4)	**8 (10)**
Total Cetaceans	***11 (35)***	***5 (8)***	***16 (43)***

Cetacean Sightings by Vessel Activity – Cetaceans were sighted most often from the *Duke* during non-seismic periods and most often from the *Synergy* while it was moving (Table 7.3). On both vessels, most cetacean sightings (~63%) occurred on the transits to and from Wainwright which were non-seismic periods of vessel movement.

TABLE 7.3. Number of cetacean sightings by seismic status or vessel activity from the *Duke* and the *Synergy* during Statoil's seismic survey and geotechnical coring operations in the Chukchi Sea, 6 Aug – 27 Sep 2011.

Vessel Activity or Seismic Status	Sightings
Duke **Seismic**	1
Duke **Non-Seismic**	10
Duke Total	***11***
Synergy **Stationary**	1
Synergy **Stationary Coring**	0
Synergy **Moving**	4
Synergy Total	***5***

Seal Sightings

Both vessels had a combined total of 121 sightings of 123 seals during the 2011 operations. Most seals were sighted from the *Duke* and the majority of these (~54%) were bearded seals. The *Synergy* had only 12 seal sightings and the majority of these (83%) were unidentified seal and pinniped sightings (Table 7.4).

TABLE 7.4. Number of seal sightings (number of individuals) from the *Duke* and the *Synergy* during Statoil's seismic survey and geotechnical coring operations in the Chukchi Sea, 6 Aug – 27 Sep 2011.

Species	*Duke*	*Synergy*	*Total*
Seals			
Bearded Seal	59 (61)	0 (0)	***59 (61)***
Ringed Seal	18 (18)	2 (2)	***20 (20)***
Spotted Seal	1 (1)	0 (0)	***1 (1)***
Unidentified Pinniped	12 (12)	5 (5)	***17 (17)***
Unidentified Seal	19 (19)	5 (5)	***24 (24)***
Total Seals	***109 (111)***	***12 (12)***	***121 (123)***

Seal Sightings by Vessel Activity – In contrast to cetacean sightings, the majority of the Duke's seal sightings (~64%) occurred during seismic activity (Table 7.5). The *Synergy* sighted fewer seals overall and the majority of these (~67%) occurred while the *Synergy* was moving between survey areas or to and from Wainwright.

TABLE 7.5. Number of seal sightings by seismic status or vessel activity from the *Duke* and the *Synergy* during Statoil's seismic survey and geotechnical coring operations in the Chukchi Sea, 6 Aug – 27 Sep 2011.

Vessel Activity or Seismic Status	Sightings
Duke **Seismic**	70
Duke **Non-Seismic**	39
Duke Total	***109***
Synergy **Stationary**	2
Synergy **Stationary Coring**	2
Synergy **Moving**	8
Synergy Total	***12***

Pacific Walrus Sightings

The *Duke* and *Synergy* had a combined 81 sightings of 147 individual Pacific walruses during Statoil's 2011 operations (Table 7.6). Most of these sightings (~75%) occurred from the *Duke*, and a large percentage of the *Duke's* sightings (~72%) occurred on just two days, 18 Aug and 28 Aug.

Pacific Walrus Sightings by Vessel Activity – The majority of the *Duke's* sightings (~67%) occurred during periods of seismic activity (Figure 7.7). This was largely caused by the high number of walrus sighted on 18 Aug during a period when seismic activity from the *Duke* was ongoing.

TABLE 7.6. Number of Pacific walrus sightings (number of individuals) from the *Duke* and the *Synergy* during Statoil's seismic survey and geotechnical coring operations in the Chukchi Sea, 6 Aug – 27 Sep 2011.

Species	*Duke*	*Synergy*	*Total*
Pacific Walruses	61 (98)	20 (49)	***81 (147)***

TABLE 7.7. Number of walrus sightings by seismic status or vessel activity from the *Duke* and the *Synergy* during Statoil's seismic survey and geotechnical coring operations in the Chukchi Sea, 6 Aug – 27 Sep 2011.

Vessel Activity or Seismic Status	Sightings
Duke **Seismic**	41
Duke **Non-Seismic**	20
Duke Total	***61***
Synergy **Stationary**	1
Synergy **Stationary Coring**	2
Synergy **Moving**	17
Synergy Total	***20***

Estimated Number of Marine Mammals Present and Potentially Affected

Disturbance and Safety Criteria

The NMFS required that distances to received sound levels of ≥180 dB and ≥190 dB (rms) be used to implement mitigation measures for cetaceans and seals respectively. The USFWS required that distances to RSLs of 180 dB and 190 dB (rms) be used to implement mitigation measures for Pacific walruses and polar bears, respectively. Table 7.8 shows the final measured sound radii from the *Duke* and the *Synergy*, respectively. The Synergy activities did not produce sounds ≥180 dB (rms).

Estimates from Direct Observations

All sightings data were included in the following exposure estimates based on direct observations, regardless of whether they met the data-analysis criteria described in Chapter 4.

Cetaceans

One cetacean sighting occurred from the *Duke* while airguns were operating. The closest point of approach of the individual to the mitigation airgun operating at that time was 1105 m (1208 yd). Since the ≥160 dB (rms) distance from the mitigation airgun was 840 m (Table 7.8), the individual was not likely exposed to seismic sounds ≥160 dB (rms). One cetacean sighting occurred form the *Synergy* while it was stationary in dynamic positioning mode but not coring. The CPA to this sighting was 2549 m (2788 yd) and since the measured ≥120 dB (rms) distance was 2300 km it is unlikely that the animal was exposed to ≥120 dB (rms).

Seals

Seventy-two seals (70 different sightings) were observed from the *Duke* while airguns were operating and 68 of these individuals were likely exposed to received sound levels ≥160 dB (rms). However, no seal sightings occurred within the ≥190 dB (rms) safety radius, so no mitigation measures were requested.

Table 7.8. Comparison of measurements of the ≥190, 180, 160 and 120 dB (rms) distances (in km) for sound pulses from the 4-airgun, 40 in^3 array and 10 in^3 mitigation airgun deployed from *Duke* and of the ≥160 and 120 dB (rms) distances (in km) for sound pulses from the coring and dynamic positioning operations from *Synergy* in the Chukchi Sea, Alaska, 2011.

	Duke		***Synergy***	
Received Level dB (rms)	**Full Airgun Array**	**Mitigation Airgun**	**Coring and Dynamic Positioning**	**Dynamic Positioning**
≥190	0.050	0.015	NA	NA
≥180	0.190	0.059	NA	NA
≥160	2.250	0.840	0.002	0.006
≥120	39.000	29.000	1.800	2.300

Four seals (four different sightings) were observed from the *Synergy* while it was stationary. Three of these animals were present while coring activities were taking place. The closest point of approach for two of the animals was 30 m (33 yd), and the CPA of the third animal was 300 m (328 yd). All four animals were likely exposed to received levels of continuous sounds ≥120 dB (rms).

Pacific Walruses

Sixty-two Pacific walrus (42 different sightings) were observed from the *Duke* while airguns were operating and of these, 57 walruses (38 sightings) were likely exposed to received sound levels ≥160 dB (rms). Based on the final SSV measurement results, two walruses in two separate sightings were likely exposed to RSLs ≥180 dB (rms). Power downs were requested and implemented in both cases.

Four Pacific walrus (three different sightings) were observed from the *Synergy* while it was stationary; of these, three individuals (two sightings) occurred while coring was taking place. The closest points of approach of these two sightings were 10 m (11 yd) and 100 m (109 yd). All three animals were likely exposed to received levels of continuous sounds ≥120 dB (rms).

Estimates Extrapolated from Density

The following estimates based on density calculations assume that all mammals present were well below the surface where they were exposed to RSLs at various distances as reported in Chapter 3 and summarized in Tables 4.1 and 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). Some marine mammals may also have moved away from the path of the *Duke* as it was surveying, and the *Synergy* as it was coring, in an avoidance response to the approaching vessel, and airgun and, may have stayed away from the in an avoidance response to the coring sounds. In the case of cetaceans and walrus, the total estimated number of exposures based on non-seismic densities represents the number of animals that would have been exposed had they not shown any avoidance of the airguns or the ship.

TABLE 7.9. Estimated numbers of individual marine mammals exposed to either pulsed seismic sounds at received levels of ≥160 dB (rms) or continuous sounds from coring activities ≥120 dB (rms) based on densities observed during seismic and non-seismic periods during all of Statoil's 2011 site surveys, 6 Aug – 27 Sep 2011. All fractional values in the table have been rounded up to the nearest whole number. The totals for cetacean and seal species groups were calculated on the sum of the densities within that group, not the sum of the rounded up estimates for each individual species.

	Estimated No. Individuals						**Requested Take**	
	Seismic Densities			**Non-seismic Densities**				
Species	**Mean**	**LCL**	**UCL**	**Mean**	**LCL**	**UCL**	**Mean**	**Max**
Cetaceans								
Gray whale	0	--	--	18	5	39	44	88
Unid. mysticete whale	0	--	--	4	1	8	--	--
Total Cetaceans	***0***	***--***	***--***	***21***	***8***	***49***	77	184
Seals								
Ringed Seal	48	17	112	38	10	86	804	1331
Spotted Seal	3	--	--	0	--	--	16	26
Bearded Seal	91	36	218	48	15	109	27	52
Unid. Seal	28	5	60	37	10	84	--	--
Unid. Pinniped	16	3	34	9	2	18	--	--
Total Seals	***185***	***90***	***458***	***131***	***26***	***287***	848	1418
Pacific walrus	87	39	212	138	59	333	--	--

Cetaceans

Based on the density estimates and the area exposed to seismic sounds ≥160 dB (rms) or continuous sounds ≥120 dB (rms) during coring operations, ~21 individual cetaceans, mostly gray whales, may have been exposed to RSLs at or above these thresholds if they showed no avoidance of the operations (Table 7.9). This total is substantially lower than both the mean and maximum estimates (41 and 88 individuals, respectively) presented in the IHA application.

The lower estimated exposures based on the field data resulted from several factors. First, the measured distance of the 120 dB (rms) sound isopleth around coring operations was much shorter than that estimated in the application materials. Additionally, fewer cores were collected at fewer sites than proposed in the application. Lastly, observed densities of cetaceans were slightly lower than those used in the IHA application.

Seals

Based on the density estimates and area exposed to airgun sounds ≥160 dB (rms) during site surveys or continuous sounds ≥120 dB (rms) during coring operations, ~185 seals, including ~91 bearded seals, ~48 ringed seals, and ~3 spotted seals, may have been exposed to RSLs at or above the disturbance thresholds if they showed no avoidance of the operations (Table 7.9).

These totals are substantially lower than both the mean and maximum estimates presented in the IHA application for ringed seals (803 and 1331 individuals, respectively) and lower than the IHA application estimate for spotted seals (16 and 26 individuals, respectively). The observed non-seismic densities of ringed seal (0.042 and 0.005) were substantially lower than expected (0.3668 and 0.2458) for both the summer and fall periods, respectively. Conversely, bearded seal densities based on field observations in summer and fall, 0.046 and 0.111 respectively, were higher than the expected densities used in the IHA application (0.014 and 0.014.

Pacific Walruses

Based on the density estimates and area exposed to seismic sounds ≥160 dB (rms) during site surveys or continuous sounds ≥120 dB (rms) during coring operations, ~138 Pacific walrus may have been exposed to RSLs at or above these thresholds if they showed no avoidance of the operations (Table 7.9).

Acoustic Detections and Visual Observation in 2010

Bowhead whales, Pacific walruses, and bearded seals were detected acoustically using a fixed acoustic receiver array in 2010. Some bowhead whale vocalizations were localized while other bowhead whale, Pacific walrus, and bearded seal vocalizations were detected and tallied.

Cetaceans

Localized bowhead whale calls were concentrated above the receivers, while bowhead whales were observed closer to the coast during transits to Wainwright (Fig 7.2). However, visual and acoustic detections are difficult to compare as the majority of acoustic detections occur after vessels left the site (Fig. 7.3).

Bearded Seals

The majority of acoustic detections of bearded seal vocalizations occurred after vessels left the site (Fig. 7.4). The highest periods of visual observations of bearded seals did not occur in conjunction with high acoustic detections (Fig. 7.4).

Pacific Walruses

Increased acoustic detections of Pacific walrus vocalizations were related to the high number of Pacific walrus observations between 28 and 31 Aug 2010 as a large number of Pacific walrus moved from the receding ice edge towards the Alaskan Chukchi Sea (Fig. 7.5). Counts of walrus calls remained high throughout early to mid- Sep 2010 at recorders closer to Wainwright than the survey area; however, a corresponding high rate of visual detections at the seismic survey site was less evident (Fig. 7.5).

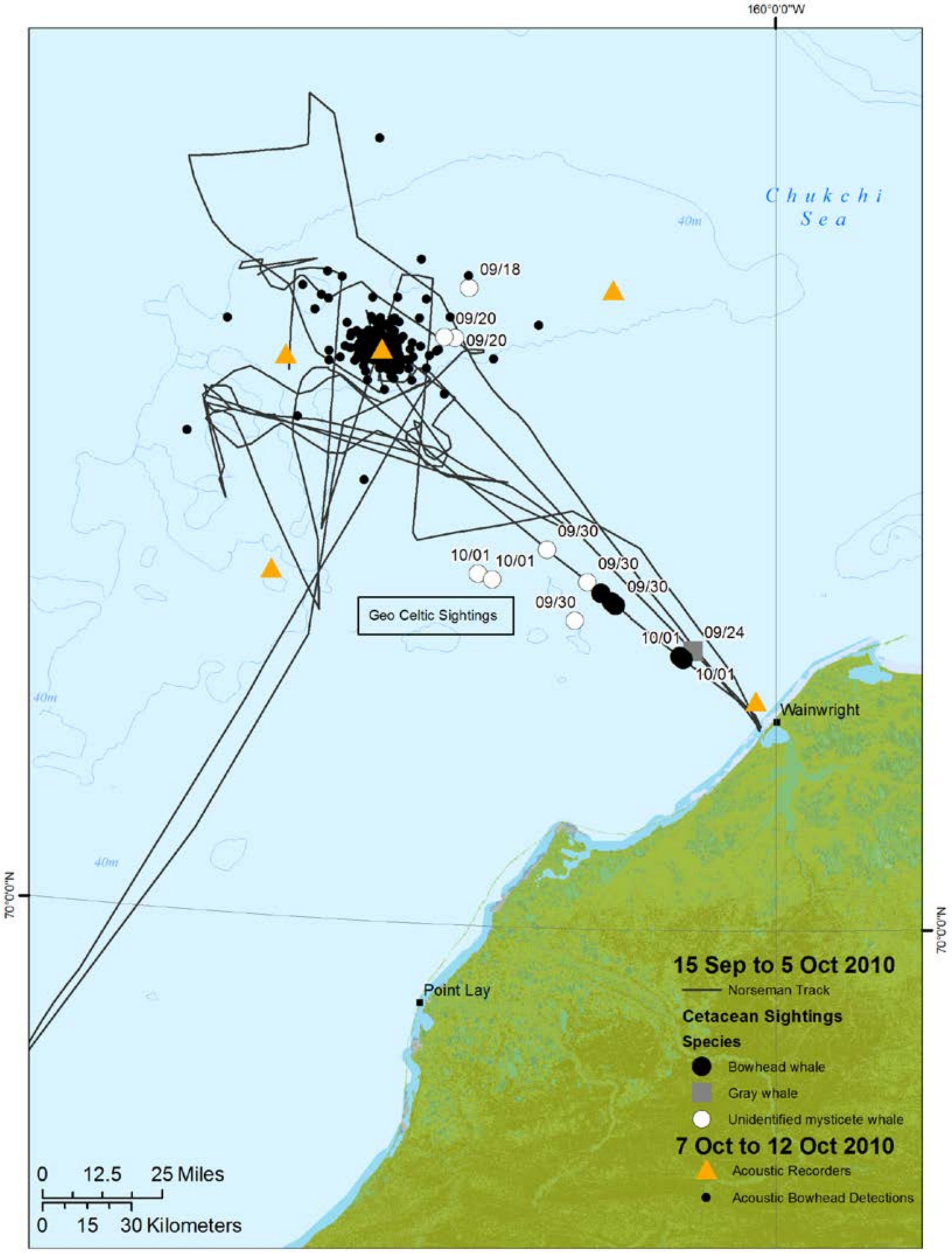

FIGURE 7.2. Visual observations of cetaceans and acoustic detections of bowhead whales during the end of Statoil's 2010 seismic survey. Acoustic detections are shown by small black circles and ranged in time from 7 Oct to 12 Oct. Visual detections of bowhead whales (black circles), gray whales (gray squares) and unidentified mysticete whales (white circles) ranged in time from 18 Sep to 1 Oct. Sightings were primarily recorded by MMOs on the *Norseman* (vessel track shown in black) however three sightings were from MMOs aboard the *Geo Celtic*.

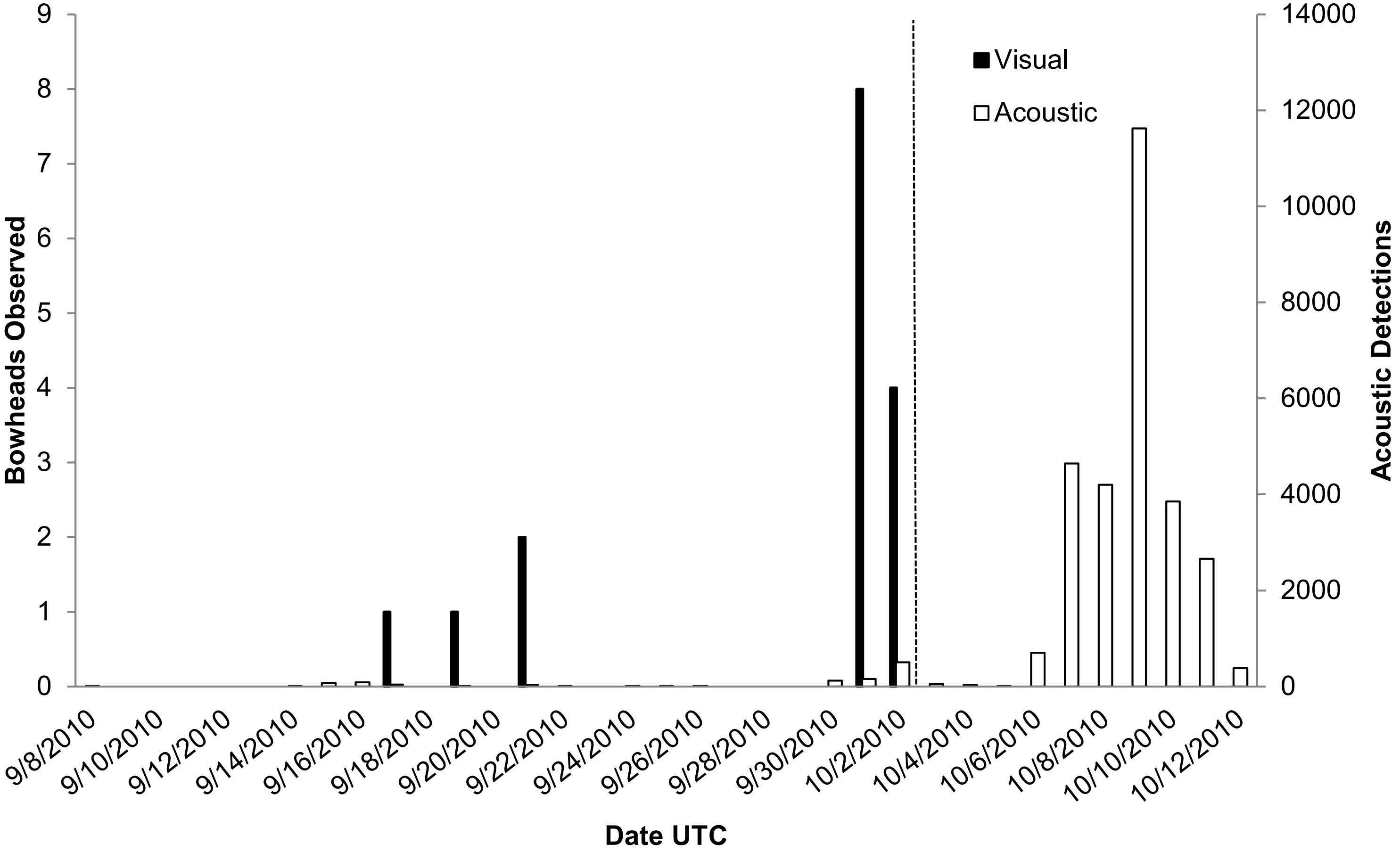

FIGURE 7.3. Daily count of acoustic bowhead detections and number of bowheads and unidentified mysticete whales observed during Statoil's 2010 seismic survey. The dashed line indicates the end of visual observation due to the end of the seismic survey.

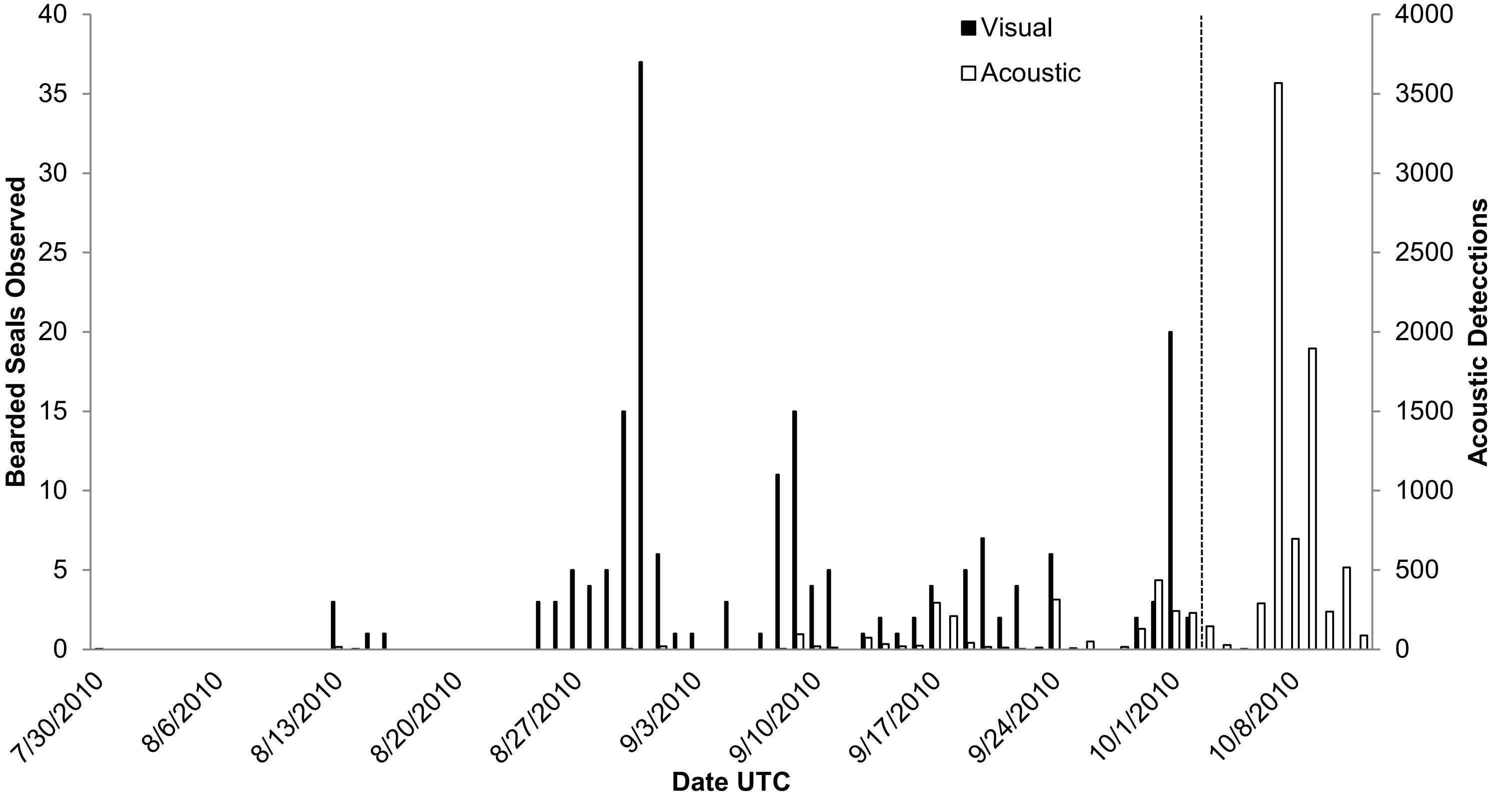

FIGURE 7.4. Daily count of acoustic bearded seal detections and number of bearded seals observed during Statoil's 2010 seismic survey. The dashed line indicates the end of visual observation due to the end of the site survey.

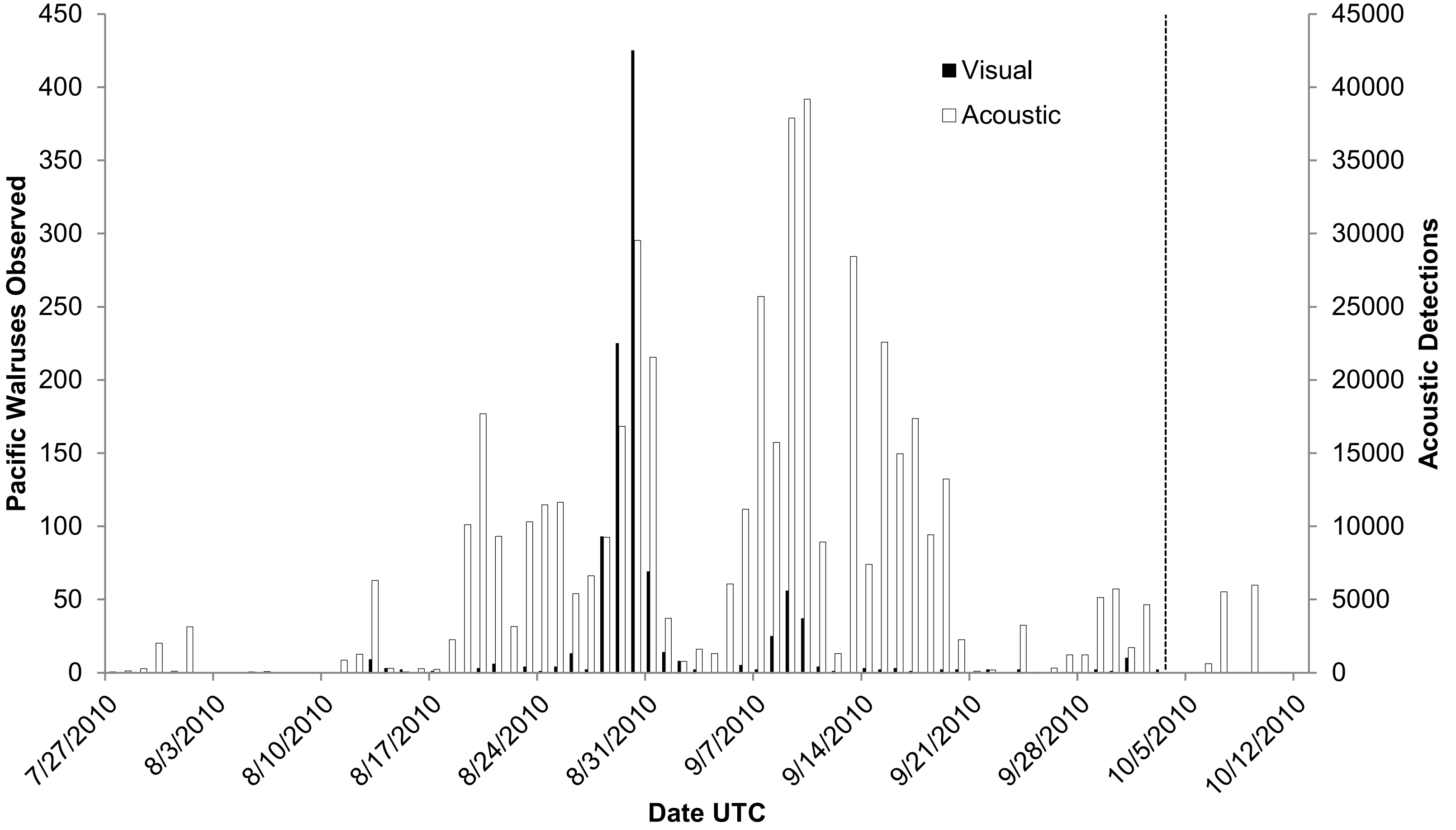

FIGURE 7.5. Daily count of acoustic Pacific walrus detections and number of Pacific walruses observed during Statoil's 2010 seismic survey. The dashed line indicates the end of visual observation due to the end of the site survey.

Night Observations

Observers on both vessels performed routine observations at night using night vision devices (NVDs) to continue to test and assess their usefulness for monitoring in darkness. The NVDs used were U.S. Night Vision's model AN/PVS-7B, a third generation auto-gated night vision goggles. One NVD was on both the *Duke* and the *Synergy*. The PVS-7B is a dual eye configuration night vision device that amplifies ambient light making observation of low light areas possible. It has a 40° field of view, a 3X optical magnifier, and has a focal range from 25 cm to infinity. The device can either be held up to the eyes or it can be worn over the eyes 'hands-free' with the use of a head strap.

Figure 7.6. Image of US Nightvision's model AN/PVS-7B mounted to optional headstrap.

Observers on the *Duke* used the device several times an hour during darkness hours and observers on the *Synergy* used them opportunistically under a variety of conditions. The typical observation session by observers on the the *Duke* was 5-10 minutes in length, after which time eye fatigue and difficulty in holding the goggles up to the eyes caused the quality of observation to diminish substantially. The MMOs typically conducted 5-10 minute observations with the device followed by an equal amount of time with the naked eye. The observers on the *Duke* did not find the head strap tolerable as it amplified eye fatigue, therefore, most observations were conducted by holding the goggles up to the eyes. Observers also found that, depending on the temperature of the air, the inner lens would fog up before the eye fatigue caused the observer to take a break. Observations with NVDs on the *Synergy* were conducted less consistently as MMOs were not on watch 24 hours a day. *Synergy* observers were able to conduct longer continuous watches with the NVDs because they did not stay on watch throughout all hours of darkness.

The NVDs were most useful when there was still a small amount of ambient light present. These included nights with low cloud cover (excluding fog), or no clouds and some moon light. The low cloud cover helped to reflect the vessel lights and greatly increased the ambient light in the water around the vessel. Nights with fog, no ambient light, or heavy seas made observations nearly impossible and the devices were not often used in those conditions. Additionally, the vessels deck lights and/or internal bridge lights often severely limited the usefulness of the night vision goggles from inside the Bridge. These lights often obscured certain areas around the vessels and required the observer to focus only on those areas without strong vessel lights. Observers on the *Duke* estimated the device's effective range to be between 10 m (33 ft) and 500 m (1640 ft) depending on the lighting and environmental conditions.

Observers on both vessels were able to occasionally sight jellyfish and seabirds if they were near the vessel and the sighting conditions were good. Only two marine mammal sightings were made using NVDs and both sightings were of Pacific walrus sighted by observers on the *Synergy*. The first animal was initially sighted with the unaided eye in an area illuminated by vessel lights and subsequently spotted with the NVD. The second sighting was of a pair of Pacific walrus, also initially detected with the unaided eye and then subsequently spotted with the NVDs. Both of these sightings occurred while the *Synergy* was stationary and may have aided the observer in detecting the walrus. No marine mammals were sighted from the *Duke* during darkness hours, with or without the use of NVDs, despite the *Duke* conducting the majority of night observations. The lack of nighttime sightings, especially from the *Duke*, was likely due to the limitations of the observers (eye fatigue, areas on vessel free from excessive light or glare) and of the device to perform in various environmental conditions (i.e. high sea states or fog).

In 2010, Statoil conducted observations from their seismic survey vessel, *Geo Celtic*, using a 360° infrared (IR) camera. This device utilized the temperature difference between marine mammals and their surrounding environment to display and record direction and distance of marine mammals relative to the vessel. The IR camera system had environmental limitations similar to NVDs; ineffective in fog, high sea state, etc., but it also had advantages. The images from the camera were displayed on three high resolution computer monitors that could be dimmed and observed for extended periods without eye fatigue. During favorable sighting conditions, a high contrast object was easily detected by the observer. The camera also had an auto detect system that would alert the observer to potential detections (currently configured only for whale blows). Although the auto detect function was not always reliable (false detections generated by waves, spray and fog) it did keep the observer alert to potential marine mammals. This particular system also allowed the observer to record all or segments of the video stream coming from the camera. This is a very useful function for retrospective analysis and comparison to optical observations. This particular IR camera system is experimental and not currently commercially available. Although it is a promising technology, it will require further testing and evaluation before it can be implemented as a regular monitoring tool.

A recommended next step in evaluating these two technologies would be to conduct observations with a pair of observers utilizing both a commercially available IR system and an optical NVD system. The IR observer may be able to detect potential marine mammals more consistently, experiencing less eye fatigue, while the optical observer could confirm observations and potentially identify the species of marine mammal. The duration of time that NVDs could be used by an observer would depend on vessel activity (moving, surveying, stationary, etc.), observer capacity (eye fatigue), and environmental conditions (fog, ambient light, sea state, etc.). We estimate that an observer could only utilize the NVDs for half of their night observation shift (10-15 min with NVDs followed by equal time with unaided eye), while the IR observer could observe the IR images on screen nearly continuously. An optimal observation schedule would have two observers on watch alternating between the NVDs and the IR system at set intervals throughout the night.