bp

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April 10, 2013

Shane Guan
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Submittal of BPXA Final 90-Day Report for Marine Mammal Monitoring during Simpson Lagoon OBC Seismic Survey, Beaufort Sea, Alaska, July – September 2012

Dear Mr. Guan:

Please find attached the 90-day Report for Marine Mammal Monitoring during BPXA Simpson Lagoon OBC Seismic Survey in the Beaufort Sea of Alaska from July to September 2012.

In accordance with the Incidental Harassment Authorization issued for the Simpson Lagoon OBC Seismic Survey, BP Exploration Alaska Inc. (BPXA), submitted a draft version of this report to the National Marine Fisheries Service for review within 90 days of the completion of the project.

The recommendations and comments received from your office have been addressed and incorporated into this final version of the 90-Day Report. The raw marine mammal observer data are available upon request.

Should you have any questions or require additional information, please do not hesitate to contact me at (907) 564-4383 or Bill.Streever@bp.com.

Sincerely,

Bill Streever

Bill Streever

NMFS 90-Day Report for Marine Mammal Monitoring and Mitigation during BPXA Simpson Lagoon OBC Seismic Survey, Beaufort Sea, Alaska
July to September 2012

Prepared for:

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March 2013

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ACRONYMS AND ABBREVIATIONS

°	degree(s)
3D	three-dimensional
AEWC	Alaska Eskimo Whaling Commission
AKDT	Alaska Daylight Time
ASL	above sea level
Bf	Beaufort
BPXA	BP Exploration (Alaska), Inc.
CAA	Conflict Avoidance Agreement
Com-Center	Communication and Call Center
dB	decibel(s)
dB re 1 μPa (rms)	decibel(s) referenced to a pressure of 1 micropascal
ESA	Endangered Species Act
ft	foot/feet
hr	hour(s)
HSSE	Health, Safety, Security and Environment
IHA	Incidental Harassment Authorization
in^3	cubic inch(es)
km	kilometer(s)
kt	knot(s)
LOA	Letter of Authorization
m	meter(s)
mi^2	square mile(s)
min	minute(s)
MMPA	Marine Mammal Protection Act
M/V	Motor Vessel
NMFS	National Marine Fisheries Service
OBC	ocean bottom cable
PSO	protected species observer
rms	root mean square
SSV	sound source verification
USFWS	U.S. Fish and Wildlife Service
yd	yard(s)

1.0 INTRODUCTION

BP Exploration (Alaska), Inc. (BPXA), conducted a three-dimensional (3D) ocean bottom cable (OBC) seismic survey in the Simpson Lagoon area during the 2012 open water season. Seismic cable and node deployment began on July 26, followed by source testing beginning on July 29. Source acquisition was completed on September 7, and the survey project was fully demobilized on September 18. The Simpson Lagoon area is located in the Beaufort Sea, Alaska, with the approximate boundaries between 70°28'N and 70°39'N and between 149°24'W and 149°55'W, between Oliktok and Milne points.

Marine seismic surveys emit sound energy into the water and have the potential to affect marine mammals, given the reported auditory and behavioral sensitivity of many such species to underwater sounds. Behavioral, distributional, or (if they occur) auditory effects could constitute a "take" under provisions of the Marine Mammal Protection Act (MMPA) and the Endangered Species Act (ESA). The National Marine Fisheries Service (NMFS) has jurisdiction over the whale and seal species that were likely to be encountered during the project and provided authorization to conduct the seismic survey through an Incidental Harassment Authorization (IHA). The IHA included provisions to minimize the possibility that marine mammals would be exposed to potentially harmful seismic sounds and to reduce behavioral disturbances that could be considered as a "take" under the MMPA.

In addition, regulations in the MMPA require that IHA applicants planning activities in Arctic waters provide a Plan of Cooperation that identifies measures to minimize adverse effects on the availability of marine mammals for subsistence purposes. BPXA met with representatives of the community of Nuiqsut, the Alaska Eskimo Whaling Commission (AEWC), the North Slope Borough, and others to discuss appropriate measures to be implemented during the 2012 Simpson Lagoon seismic survey with the purpose of avoiding conflicts with the subsistence hunt. These measures were included in the Conflict Avoidance Agreement (CAA) that was signed on June 4, 2012 (AEWC 2012).

A marine mammal monitoring and mitigation program was conducted in compliance with the issued IHA to avoid or minimize the BPXA seismic survey's potential effects on marine mammals, as well as to communicate with local subsistence communities. This required that trained protected species observers (PSOs) on-board source vessels detect marine mammals within or about to enter the estimated safety zone radii (190 decibels [dB] for pinnipeds and 180 dB for cetaceans) and initiate an immediate power-down or shut-down of the airguns, when needed.

This 90-day report describes the methods and results for the marine mammal mitigation and monitoring program. It is required to meet the following objectives:

1) Provide real-time sighting data needed to implement the mitigation requirements.
2) Estimate the numbers of marine mammals potentially exposed to seismic pulses exceeding sound levels of 160 dB.
3) Determine the reactions (if any) of marine mammals potentially exposed to seismic sounds.

2.0 SUMMARY OF BPXA'S SIMPSON LAGOON OBC SEISMIC SURVEY

BPXA conducted a 3D OBC seismic survey in 2012 in the Simpson Lagoon area, Beaufort Sea, Alaska. Seismic cable and node deployment began on July 26, followed by source testing that began on July 29. Source acquisition was completed on September 7, and the survey project was fully demobilized on September 18 (see Figure 2.1).

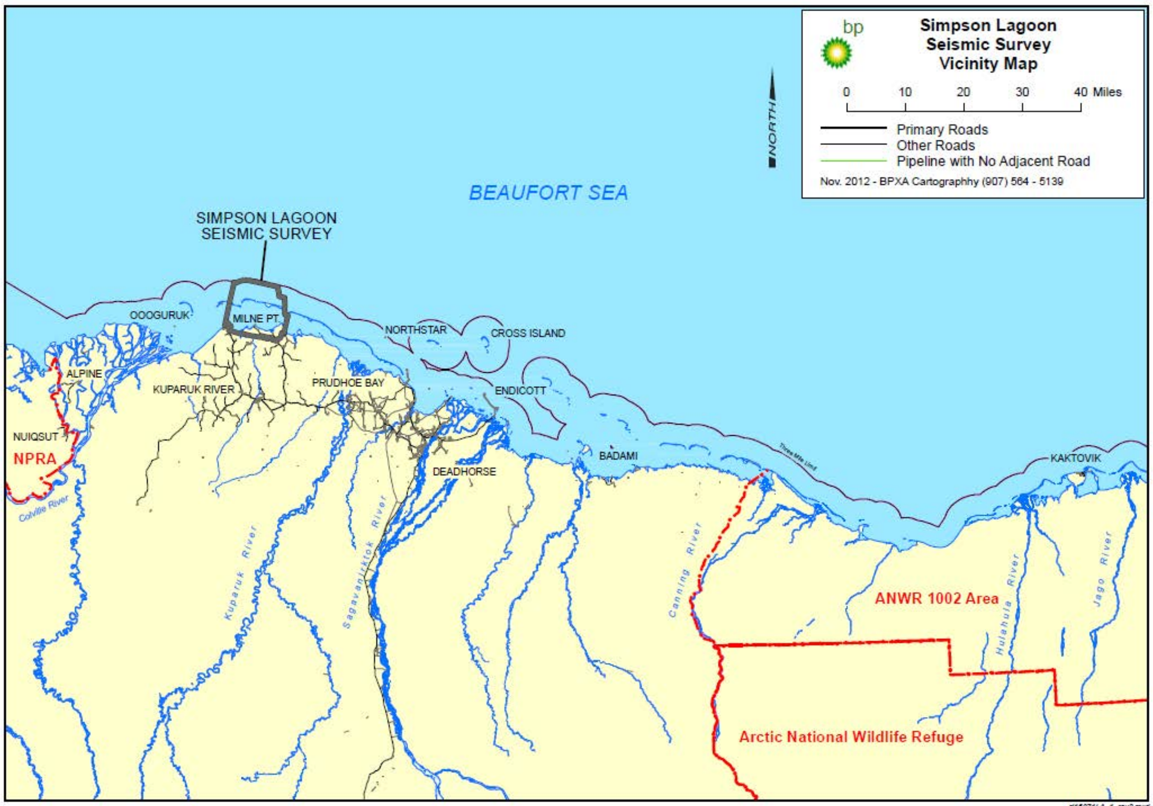

Figure 2.1 Overview of Simpson Lagoon seismic survey area.

Marine seismic acquisition, or a seismic survey, involves the transmission of sound pulses into the water at regular intervals. This is done by releasing compressed air from an array of sleeve-type "airguns." The air releases create mainly low-frequency sound pulses that are directed primarily downward through the rock below the seafloor in order to study characteristics of the rock strata. However, some of the sound energy from the airgun array propagates horizontally through the water as well. Therefore, seismic sounds may be detectable underwater at a substantial distance from the area of activity, depending on ambient conditions and the sensitivity of the receptor (Richardson et al. 1995). Depending on the size and source levels of the airgun array, some seismic pulses are strong enough that—even allowing for gradual loss with increasing distance—they may remain detectable by marine mammals (and other marine animals) at distances of approximately 50 to 100 kilometers (km) at times of low ambient underwater sound (Richardson et al. 1999). Seismic pulses are known to cause avoidance reactions and other behavioral changes in some baleen whales (e.g., bowhead [*Balaena mysticetus*], gray [*Eschrichtius robustus*], and humpback [*Megaptera novaeangliae*]), occurring within a distance of several miles of the sound source (Miller et al. 2005). Although the hearing sensitivity of toothed whales is thought to be poor at low frequencies—which characterize the airgun pulses—the sounds are strong enough that toothed whales can likely detect them several tens of km away. Seismic pulses may have disturbed several marine mammal species occurring in the area.

The seismic survey activities conducted in the Simpson Lagoon had the potential to disturb marine mammals and followed the guidelines of the MMPA. A disturbance event can occur when marine mammals near the seismic activities change their behavior in response to the sounds or experience a temporary reduction in hearing sensitivity. The type of behavioral reaction depends on the species, the behavior of the animal at the time of reception of the stimulus, as well as the distance and the received level of the sound relative to ambient sound levels. Under the MMPA, BPXA received an IHA authorizing a take, by Level B harassment, for a small number of marine mammals incidental to conducting an open-water OBC seismic survey. The presence of PSOs on-board the seismic source vessels was part of the mitigation measures outlined in the IHA issued by the NMFS. BPXA also requested a Letter of Authorization (LOA) (BPXA 2012) from the U.S. Fish and Wildlife Service (USFWS) allowing unintentional harassment of polar bears (*Ursus maritimus*) and Pacific walrus (*Odobenus rosmarus*) incidental to the planned seismic activities and harassment of polar bears for the protection of human life while conducting survey activities.

2.1 Purpose

The purpose of the OBC seismic survey was to replace and augment existing datasets by providing better-quality, higher-resolution seismic data to image the Milne Point Unit field. The existing datasets included a 2001 OBC seismic survey over a portion of Simpson Lagoon and a 2007 Milne Point vibroseis survey (the latter was primarily onshore, with some receivers along the coastline). The summer 2012 data were acquired to improve BPXA's understanding of the reservoir, allowing for more efficient reservoir management.

2.2 Project Details

The Simpson Lagoon OBC seismic survey used receivers (i.e., hydrophones and geophones) connected to a cable that was deployed from a vessel to the seabed or was inserted in the seabed in very shallow water near the shoreline. OBC seismic surveys in the Arctic are typically used to acquire seismic data in water that is too shallow for towed streamer operations or too deep to have grounded ice in winter. Data acquired through this type of survey allow generation of a 3D subsurface image of the reservoir area. Generating a 3D-image requires the deployment of parallel cables spaced close together over the area of interest. OBC seismic surveys require using multiple vessels for cable deployment and recovery, data recording, airgun operation, re-supply, and support. The 3D OBC seismic survey in Simpson Lagoon was conducted by CGGVeritas.

The following sections describe in more detail the various components of the OBC seismic survey, such as timing and location (Section 2.2.1), seismic source arrays (Section 2.2.2), receivers and recording units (Section 2.2.3), survey design (Section 2.2.4), and vessels and other equipment (Section 2.2.5).

2.2.1 Dates, Duration, and Region of Activity

BPXA received an IHA for the period of July 1 to October 15, 2012, from NMFS. Transportation of vessels to West Dock occurred by road in late May and early June. The first cables were laid out on July 26, sound source verification began on August 29, and seismic data acquisition began on August 3. To limit potential impacts on bowhead whale migration and the subsistence hunt, no airgun operations occurred in areas north of the barrier islands after August 25, in accordance with the CAA. Data acquisition inside the barrier islands was completed on September 7. Vessels were demobilized at West Dock or Milne Point Unit, and the project was fully demobilized on September 18.

The Milne Point field lies about 35 miles (mi) northwest of Prudhoe Bay, Beaufort Sea, Alaska. The approximate boundaries of the total surface area are between 70°28'N and 70°39'N and between 149°24'W and 149°55'W, between Oliktok and Milne points on the Beaufort Sea coast in Simpson Lagoon (see Figure 2.2). The final survey area encompassed 83 square miles (mi^2) in Simpson Lagoon. About 42 mi^2 (50.1 percent) of the survey area was located inside the barrier islands in waters with bottom depths of 0 to 9 feet (ft), while 28 mi^2 (34.3 percent) was outside the barrier islands in waters with bottom depths of 3 to 45 ft. The remaining 13 mi^2 (15.6 percent) was located on land (i.e., onshore and barrier island), which was used solely for deploying the receivers.

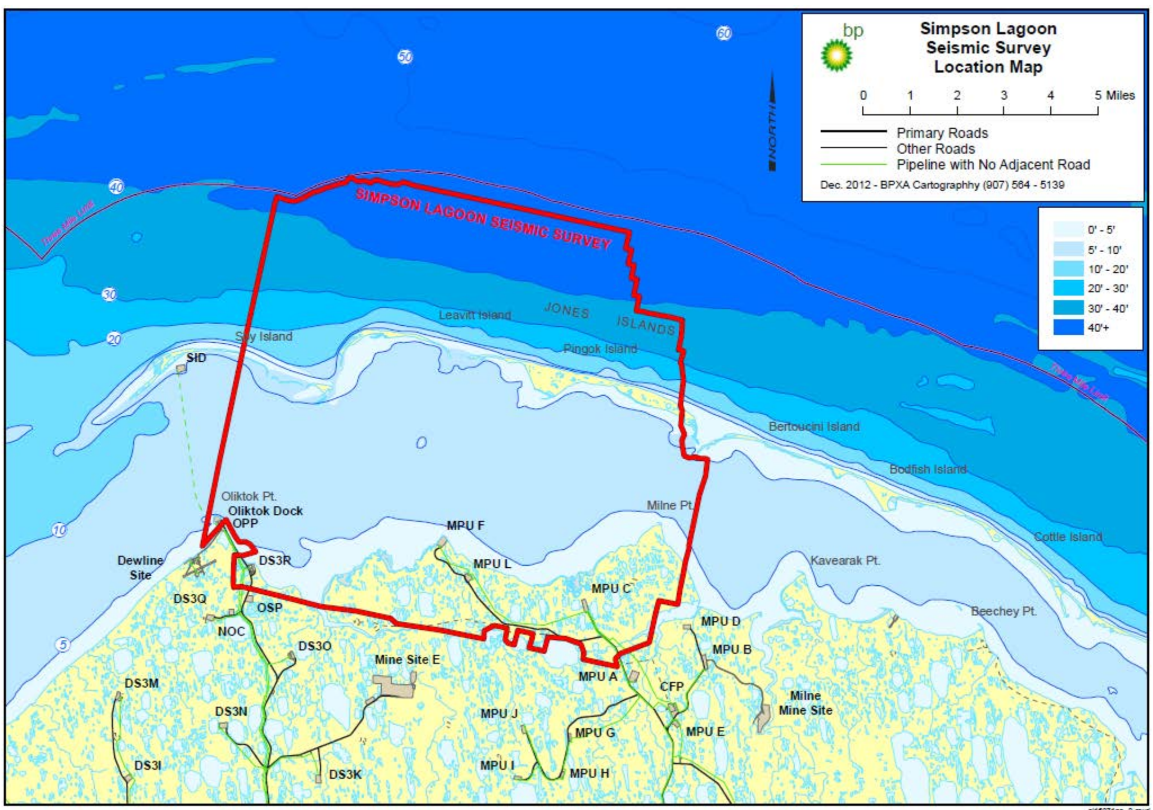

Figure 2.2 Area of Simpson Lagoon OBC seismic survey in summer 2012.

2.2.2 Source Arrays

Three source vessels were used during this seismic survey: two main source vessels, the Motor Vessel (M/V) *Resolution* and M/V *Margarita,* and one mini-source vessel, M/V *Storm Warning*. *Resolution* and *Margarita* collected data from outside and inside the barrier islands, while *Storm Warning* worked only the shallower waters inside the barrier islands. *Resolution* and *Margarita* towed two arrays, while *Storm Warning* carried one array. Each array contained eight 40-cubic-inch (in^3) airguns, totaling 16 guns per main source vessel (*Resolution* and *Margarita*) with a total discharge volume of 2 × 320 in^3, or 640 in^3. The 640-in^3 arrays had an estimated sound source level of approximately 223 dB re 1 µPa (root mean square [rms]). The mini-source vessel (*Storm Warning*) contained one array with eight 40 in^3 airguns for a total discharge volume of 320 in^3. Estimated sound source level of this 320 in^3-array was 212 dB referenced to 1 micropascal (root mean square) (dB re 1 µPa (rms)). Table 2.1 summarizes the specifications of the airgun arrays.

For operational reasons, the 640 in^3 array was used only outside of the barrier islands. The largest discharge volume used inside the barrier islands was 320 in^3. The arrays were towed at a distance of approximately 8 to 10 meters (m) (approximately 26 to 32 feet [ft]) from the source vessels at depths of 1.8 m (6 ft) outside of the barrier islands and 1.1 m (3.5 ft) inside the barrier islands, depending on bathymetry. Source vessels traveled along predetermined lines at an average speed of 5.6 kilometers/hour (km/hr) (3 knots [kt]). Each source vessel fired shots every 8 seconds, resulting in 4-second shot intervals in situations when two vessels were operating simultaneously (i.e., “ping-pong”). The advantage of source vessels alternating shots is that more data can be acquired in a shorter time. When weather and operational conditions allowed, seismic data acquisition was conducted 24 hr/day.

Table 2.1 Specifications of the 640-in^3 and 320-in^3 airgun arrays

Array parameter	640-in^3 array	320-in^3 array
Number of guns	Sixteen 2,000-psi sleeve airguns of 40-in^3 divided over two subarrays of eight guns	Eight 2,000-psi sleeve airguns of 40 in^3
Zero-to-peak	12.5 bar-m (242 dB re 1µPa @1 m)	4.26 bar-m (233 dB re 1µPa @1 m)
Peak-to-peak	23.1 bar-m (247 dB re 1µPa @1 m)	7.92 bar-m (238 dB re 1µPa @ 1 m)
rms pressure	1.44 bar-m (223 dB re 1µPa @ 1 m)	0.39 bar-m (212 dB re 1µPa @1 m)

Source: Warner and Hipsey (2011)
Notes: dB re 1µPa @1 m = decibels relative to 1 microPascal at 1 meter**,** in^3 = cubic inch, psi = pounds per square inch, rms = root mean square

2.2.3 Receivers and Recording Units

The survey area in Simpson Lagoon has bottom depths of 0 to 3 m (0 to 10 ft) between the shore and the barrier islands and 1 to 15 m (3 to 50 ft) north of the barrier islands.

Because different types of receivers were used for different habitats, the survey area was categorized by the following zones:

- *Onshore* was the area from the coastline inland.
- *Islands* referred to the barrier islands.
- *Surf* was the 0 to 6 ft water depths along the onshore coastline.
- *Offshore* was defined as depths of 3 ft or more.

This resulted in a zone with depths between 3 and 6 ft that was categorized as both surf and offshore.

The receivers deployed in water consisted of multiple hydrophones and recorder units (Field Digitizing Units) placed on Sercel ULS cables. Hydrophones were connected to the ULS cable at intervals of a minimum of 82.5 ft and secured to the ocean bottom cable. Surface markers and acoustic pingers were attached to the cable at various intervals to ensure that the battery packs were located and retrieved when needed and to determine exact positions for the hydrophones. This equipment was deployed and retrieved with cable boats. The data received at each Field Digitizing Unit were transmitted through the cables to the recorder for further processing. The recorder was installed on a boat-barge (*Alaganik/Hook Point*), which was positioned close to the area where data were being acquired.

In the surf zone, receivers (hydrophones or geophones) were either bored or flushed up to 12 ft below the seabed. These receivers transmitted data through a cable (as described above) and had line attached to facilitate retrieval. Autonomous recorders (nodes) were used onshore and on the islands. Each node was located on the ground, and its geophone was inserted into the ground by hand with the use of a planting pole. Deployment of the autonomous receiver units was done by lay-out crews on the ground using helicopters for personnel and equipment transport and support boats (for the islands). All equipment was picked up after recording was completed.

2.2.4 Survey Design

The receiver cables with hydrophones and recording units were oriented in an east-west direction. A total of 26 receiver lines were deployed at the seafloor with the total receiver line length of 264 mi. The source vessels traveled perpendicular over the offshore receiver cables along lines oriented in a north-south direction. These lines had a length of approximately 3.75 mi, with a total length of all source lines of 1,700 mi, including line turns.

2.2.5 Vessels and Other Equipment

The OBC seismic survey conducted in Simpson Lagoon involved 14 vessels as described in Table 2.2. The survey was conducted by three seismic source vessels (two main sources, M/V *Resolution* and M/V *Margarita*, and one mini source, M/V *Storm Warning*), five cable vessels, a recorder vessel and barge, two crew/support boats, and two shallow-water crew boats. All vessels were operated by CGGVeritas in accordance with permit provisions.

To deploy and retrieve receivers in water depths less than those accessible by the cable boats (i.e., surf zone), equipment such as airboats, Arktos, and jon boats were used.

Helicopters and boats were used to deploy receiver units onshore as well on the barrier islands.

Vessels and other equipment were transported to the North Slope in late May and early June by trucks. Vessel preparation included assembly of navigation and source equipment, cable deployment and retrieval systems, and safety equipment. Once assembled, vessels were launched at either West Dock or Milne Point. Deployment, retrieval, and navigation and source systems were then tested near West Dock or in the project area after July 25 and prior to commencement of seismic data acquisition.

Table 2.2 Number and type of vessels involved in the Simpson Lagoon OBC seismic survey.

Vessel Type	**Number**	**Approximate Dimensions**	**Main Activity**	**Frequency**
Source vessels: main	2	71 x 20 ft	Acquire seismic data inside and outside barrier islands	24-hr operation
Source vessel: mini	1	55 x 15 ft	Aquire seismic data inside barrier islands	24-hr operation
Recorder barge with tug boat	1	Barge: 116.5 x 24 ft Tug: 23 x 15 ft	Record seismic data	24-hr operation
Cable boats	5	42.6 x 13 ft	Deploy and retrieve receiver cables (with hydrophones/ geophones)	24-hr operation
Crew transport vessels	2	44 x 14 ft	Transport crew and supplies to and from the working vessels	Intermittently, minimum every 8 hr
Shallow-water crew and support boats	2	34 x 10.5 ft	Transport two to five people and small amounts of gear for boats operating in shallower parts of survey area	Intermittently
HSSE vessel	1	38 x 15 ft	Support SSV measurements, HSSE compliance	Intermittently
Total	**14**			

Notes: ft = feet; hr = hour; HSSE = Health, Safety, Security and Environment; SSV = sound source verification

3.0 SUMMARY OF MARINE MAMMALS IN SIMPSON LAGOON

All species of marine mammals in U.S. waters are federally protected by the MMPA. Sixteen marine mammal species are documented as occurring within or adjacent to the Simpson Lagoon OBC seismic survey area: five baleen whale species, four toothed whale species, six pinniped species, and the polar bear.

Seven marine mammal species have expected occurrence in the Simpson Lagoon area. The marine mammal species under NMFS jurisdiction most likely to occur in the Simpson Lagoon OBC seismic survey area include three cetacean species—beluga whale (*Delphinapterus leucas*), bowhead whale, and gray whale and three pinniped species—ringed (*Phoca hispida*), spotted (*Phoca largha*), and bearded (*Erignathus barbatus*) seals. The polar bear is under USFWS jurisdiction, and "takes" were requested under a separate take permit issued by USFWS (see the USFWS 90-day report for information on polar bears). Of these seven species, four are listed (or are candidates for listing) under the ESA: bowhead whale, ringed seal, bearded seal, and polar bear. Nine other marine mammal species have documented occurrence in the Simpson Lagoon area, but do not occur here regularly and, therefore, are considered to be extralimital to the project area: the harbor porpoise (*Phocoena phocoena*), narwhal (*Monodon monoceros*), killer whale (*Orcinus orca*), humpback whale, fin whale (*Balaenoptera physalus*), minke whale (*Balaenoptera acutorostrata*), hooded seal (*Cystophora cristata*), Steller sea lion (*Eumetopias jubatus*), and Pacific walrus.

The occurrence and distribution of marine mammals in the Beaufort Sea and project area are closely tied to and/or influenced by sea ice (Moore and Huntington 2008). Sea ice comes in many shapes and forms, and many marine mammal species prefer certain types of sea ice. Most of the ice-dependent pinniped species (i.e., seals and walrus) are closely tied to ice for portions or all of their lives as a platform for breeding, feeding, birthing, predator avoidance, and migration (Moore and Huntington 2008). With the documented retreat of the ice edge to locations farther offshore and often in deeper water (particularly during summer and fall) the distribution of marine mammals may be affected. A retreating ice edge in deeper offshore waters may make prey less accessible to benthic foragers such as bearded seals and walrus. However, spotted seals are known to use coastal haul-outs. Therefore, changes in sea ice extent may not affect this species as much as benthic foragers. Additionally, some cetacean species (baleen and toothed whales) appear to be expanding their distribution farther north and east into the Chukchi and Beaufort seas as the ice recedes and allows for access to waters that have historically been inaccessible because of ice cover (Moore and Huntington 2008). The following sections provide a brief summary of the species most likely to occur in the survey area. Refer to BPXA's IHA application for a more detailed literature review (BPXA 2012).

3.1 Beluga Whale

The beluga whale occurs mainly in seasonally ice-covered seas between 50°N and 80°N and is closely associated with open leads and polynyas (Reeves et al. 2002). Beluga whales in the Beaufort Sea belong to the Beaufort Sea and the Eastern Chukchi Sea stocks (Allen and Angliss 2012). Beluga whales of the Beaufort Sea Stock winter in the Bering Sea, and migrate north and west into the eastern Beaufort Sea where they spend their summers (Allen and Angliss 2012). This species commonly occurs seaward of the barrier islands during spring and fall migration. A few migrating belugas have been observed in nearshore waters of the central Alaskan Beaufort Sea during the July/August time period (Christie et al. 2010). Some individuals could be expected to travel closer to shore within or close to the OBC seismic survey area in Simpson Lagoon.

3.2 Bowhead Whale

Of the four NMFS-recognized stocks of bowhead whales, only the Western Arctic Stock (also known as the Bering-Chukchi-Beaufort Sea Stock) occurs in U.S. waters (Allen and Angliss 2012). The bowhead whale is an important subsistence species for Alaska Native communities. Based on distributional data (Shelden and Mocklin 2012), a small number of individuals from this stock is most likely to occur in or near waters of the project area during August to October during its westward migration. In May and June, most bowhead whales migrate eastward along the Beaufort Sea coast seaward of the barrier islands, although some remain to feed off Barrow. This spring migration tends to occur far offshore, seaward of Simpson Lagoon. The return westward migration, starting in August and lasting through October, also occurs primarily seaward of the barrier islands (Miller et al. 2002).

3.3 Gray Whale

Any occurrence of the gray whale in the central Beaufort Sea would be from the Eastern North Pacific Stock, which was listed as threatened under the ESA until 1994, when it was delisted (Allen and Angliss 2012). Most of the stock forages during summer in the northern and western Bering and Chukchi seas and, less frequently, in the Beaufort Sea (Allen and Angliss 2012). Sightings of small groups or individuals have been reported in the central Alaskan Beaufort Sea. Gray whales may be encountered in small numbers throughout the summer and fall, especially in the nearshore areas (NMFS 2012). The recent increase in gray whale sightings east of Barrow has been associated with decreased ice coverage, which may facilitate gray whale access to this region (Moore and Huntington 2008).

3.4 Ringed Seal

On December 10, 2010, NMFS proposed listing five subspecies of ringed seals as threatened (including the arctic subspecies that occurs in the area; 75 FR 77476). The final rule of the proposed listing is still pending. The ringed seal is the most abundant marine mammal in the Beaufort Sea (Allen and Angliss 2012). During the 1996 OBC seismic survey, 92 percent of all seal species identified were ringed seals (Harris et al. 2001). In general, distribution is strongly correlated with ice-covered waters (Kelly et al. 2010). During winter and spring, seals occupy landfast and offshore pack ice, yet, during summer and fall, ringed seals are widely distributed in open water between Barrow and Kaktovik (Kelly et al. 2010). During summer, high densities of ringed seals are associated with ice remnants.

3.5 Bearded Seal

On December 10, 2010, NMFS proposed listing one subspecies (two distinct population segments (DPS) of the bearded seal) as threatened, including the Beringia DPS, which occurs in the Beaufort Sea waters of the project area (75 FR 77496). The final rule of the proposed listing is still pending. Bearded seals that occur in the Beaufort Sea belong to the Alaska Stock (Allen and Angliss 2012). The bearded seal is the second most common seal species in the Beaufort Sea after the ringed seal (Allen and Angliss 2012; Harris et al. 2001). During July through September, bearded seals are normally found in broken ice that is unstable (Moulton et al. 2002).

3.6 Spotted Seal

In 2008, NMFS received a petition to list spotted seals as threatened. However, based on a status review, NMFS decided that a threatened status was not warranted for the Bering Sea stock of spotted seals (75 FR 65239). The spotted seal is the least common seal species in the Beaufort Sea (compared with the more abundant ringed and bearded seals). Spotted seals that occur in the Beaufort Sea belong to the Alaska Stock (Allen and Angliss 2012). During summer, spotted seals inhabit primarily the Bering and Chukchi Seas, although some individuals also occur in the western Beaufort Sea from July through September (Lowry et al. 1998).

4.0 OVERVIEW OF MARINE MAMMAL MITIGATION AND MONITORING PROGRAM

This section describes the marine mammal monitoring and mitigation measures implemented for BPXA's 2012 Simpson Lagoon OBC seismic survey. All data related to acoustic monitoring and measurements are contained in Appendix A. The marine mammal monitoring and mitigation program was designed to address requirements specified in the NMFS-issued IHA and USFWS-issued LOA (Appendices B and C, respectively). Data analysis methods and the results of the marine mammal monitoring and mitigation program are provided in Section 5.

4.1 Purpose

The main purpose of the vessel-based marine mammal monitoring and mitigation program was to ensure compliance with provisions of the IHA (issued by NMFS), LOA (issued by USFWS), and BP's Best Practice Guidelines. These provisions and guidelines aim to minimize disturbance to marine mammals and ensure documentation of potential effects on marine mammals. The PSOs on board of the vessels had two primary areas of responsibility:

- *Mitigation*: Detect marine mammals within, or about to enter, the applicable exclusion zone and initiate immediate shut-down or power-down of the airguns.
- *Monitoring*: Record numbers of marine mammals both during and in absence of seismic survey activity and document their reactions (where applicable).

4.2 Mitigation Measures

Mitigation measures that were implemented during the Simpson Lagoon OBC seismic survey are summarized below. These measures are divided into three groups:

(a) *General mitigation measures:* These applied to all vessels and aircraft involved in the survey.

(b) *Seismic survey mitigation measures:* These applied to the source vessels that operated the seismic airguns.

(c) *Mitigation measures for subsistence activities*: These applied to all vessels involved in the survey.

4.2.1 General Mitigation Measures

The general mitigation measures summarized below, as identified in the NMFS-issued IHA and USFWS-issued LOA, were implemented, where applicable, by the captain and crew of all Simpson Lagoon project vessels and aircraft for the duration of the survey. The three source vessels operated under an additional set of specific mitigation measures during airgun operations.

- Avoid concentrations or groups of whales. Operators of support vessels should, at all times, conduct their activities at the maximum distance possible from such concentrations of whales.
- Transit and cable laying vessels shall be operated at speeds necessary to ensure no physical contact with whales occurs. If any barge or transit vessel approaches within 1.6 km (1 mi) of observed bowhead whales, except when providing emergency assistance to whalers or in other emergency situations, the vessel operator will take reasonable precautions to avoid potential interaction with the bowhead whales by taking one or more of the following actions, as appropriate:
  - reducing vessel speed to less than 5 kt within 300 yards (yd; 900 ft or 274 m) of the whale(s)
  - steering around the whale(s), if possible
  - operating the vessel(s) in such a way as to avoid separating members of a group of whales from other members of the group
  - operating the vessel(s) to avoid causing a whale to make multiple changes in direction
  - checking the waters immediately adjacent to the vessel(s) to ensure that no whales will be injured when the propellers are engaged
  - reducing vessel speed to less than 9 kt when weather conditions reduce visibility
- When weather conditions require, such as when visibility drops, adjust vessel speed accordingly to avoid the likelihood of injury to whales.
- In the event that any aircraft (such as helicopters) are used to support the planned survey, the mitigation measures below would apply:
  - Under no circumstances, other than an emergency, shall aircraft be operated at an altitude lower than 1,000 ft above sea level (ASL) when within 0.3 mi (0.5 km) of groups of whales.
  - Helicopters shall not hover or circle above or within 0.3 mi (0.5 km) of groups of whales.

4.2.2 Seismic Survey Mitigation Measures

4.2.2.1 Definitions

The following measures were adopted for marine mammal sightings during the seismic program, provided that doing so would not compromise operational safety requirements: power-downs, shut-downs, ramp-ups, and the operation of a single source (40 in^3) airgun.

Safety Zone

Safety zones are defined by the estimated distance from the source to specific received levels that are related to potential physical or behavioral impacts of marine mammal species as a response to sounds generated by that source. For this seismic survey, safety zones for received sound levels of 190 decibels (dB) (for pinnipeds and polar bears in water) and 180 dB (for cetaceans and walrus) were estimated and then verified with in-field acoustic measurements (sound source verification [SSV]; see Appendix A). These safety zones were monitored by PSOs on source vessels during all vessel activities. Power-down or shut-down procedures (see below) were implemented when a marine mammal was sighted within or approaching the applicable safety zone radius while the airguns were operating.

Safety Zone Radii

The safety zone radius was measured from the airgun(s); however, the arrays were fairly close to the vessels (approximately 8 to 10 m). Therefore, the deviation from distance relative from the source vessel was small. Table 4.1 summarizes the preliminary safety zone distances (radii) to received sound pressure levels of 190, 180, 160, and 120 dB (rms) based on pre-season acoustic modeling results. These distances were used for the first 8 days of seismic testing and data acquisition, after which time the measured distances from the SSV were implemented (see Table 4.2). Distances in Table 4.2 are the distances used by PSOs on-board the source vessels. Some of these distances were rounded higher than actual measurements from the SSV to allow for errors in distance estimation by PSOs and to be highly conservative (i.e., overestimates) with respect to safety zone radii. See Appendix A for detailed reporting of SSV methods and results.

Table 4.1 Modeled safety zone radii (distances to received sound pressure levels of 190, 180, 160 and 120 dB rms) based on acoustic modeling results. These distances were used from July 29 to August 6.

INSIDE BARRIER ISLANDS Estimated Distances (m) to Received SPL (rms)				
Array volume	**190 dB pinnipeds**	**180 dB cetaceans**	**160 dB**	**120 dB**
320 in^3	200	500	1,500	5,700
40 in^3	20	60	700	3,700
OUTSIDE BARRIER ISLANDS Estimated Distances (m) to Received SPL (rms)				
Array volume	**190 dB pinnipeds**	**180 dB cetaceans**	**160 dB**	**120 dB**
640 in^3	150	1,000	5,500	44,000
320 in^3	150	1,000	N/A	N/A
40 in^3	50	50	810	16,000

Table 4.2 Measured safety zone radii (distances to received sound pressure levels of 190, 180, 160 and 120 dB rms) based on sound source verification. These distances were used August 6 to September 7.

INSIDE BARRIER ISLANDS Estimated Distances to Received SPL (rms)				
Array volume	**190 dB pinnipeds**	**180 dB cetaceans**	**160 dB**	**120 dB**
320 in^3	300	500	1,550	16,600
40 in^3	150	300	950	3,250
OUTSIDE BARRIER ISLANDS Estimated Distances (m) to Received SPL (rms)				
Array volume	**190 dB pinnipeds**	**180 dB cetaceans**	**160 dB**	**120 dB**
640 in^3	600	1,500	4,600	14,200
320 in^3	400	1,200	4,300	13,300
40 in^3	50	200	1,600	9,300

Ramp-up

A *ramp-up* is a gradual increase in the number of active airguns before line shooting or after a shut-down or power-down of airguns. The gradual increase in sound level allows marine mammals the opportunity to leave the immediate area before the airgun array reaches full volume. Ramp-up procedures were implemented by doubling the number of active airguns every 5 minutes (min) (see Section 4.2.2.2).

Safety Zone Power-down

A *power-down* is a reduction of active airguns (full or partial array) because of a marine mammal sighting within or approaching the applicable safety zone for the full or partial array (640 in^3 or 320 in^3, respectively).

Safety Zone Shut-down

A *shut-down* is the full stop of active airguns because of a marine mammal sighting within or approaching the safety zone for the single source airgun (40 in^3).

4.2.2.2 Ramp-Up Procedure

Resolution and *Margarita* used an airgun volume of 640 in^3 outside of the barrier islands, and all three vessels used an airgun volume 320 in^3 inside of the barrier islands. The ramp-up sequence (volume in in^3) for the source vessels operating at 640 in^3 was as follows: 40 in^3, 80 in^3, 160 in^3, 320 in^3, and 640 in^3. This procedure took approximately 20 min (15 min if operating at 320 in^3). Ramp-up procedures were implemented whenever (a) initiating airgun operation when greater than 10 min elapsed since shut-down of full airgun array, or (b) increasing airgun volume following a power-down. If less than 10 min elapsed since full shut-down or power-down, ramp-up procedures were not required.

An initial ramp-up or a ramp-up from a complete shut-down (i.e., no airguns operating) was initiated only if the entire 180 dB safety zone for the full array was visible and clear of marine mammals for 30 min prior to the commencement of ramp-up. The start of ramp-up was postponed if:

(a) the safety zone was inhibited in any way during the 30-min on-watch period (i.e., fog or darkness)
(b) a cetacean or walrus was sighted within the 180 dB safety zone during the 30 min watch period
(c) a pinniped or polar bear was sighted within the 190 dB safety zone during the 15 min period prior to the intended ramp-up

If the single source (40 in^3) airgun was operating, a ramp-up was initiated even if the safety zone was not visible (i.e., due to fog or darkness), because the single source was assumed to alert marine mammals of the presence of airgun sounds, with the intent to trigger marine mammals to avoid the area of operations.

The seismic operator and PSOs maintained records of the times when ramp-ups start and when the airgun arrays reach full power. The PSOs ensured that their shut-down, power-down, and ramp-up records matched those of the airgun operator.

4.2.2.3 Power-down/Shut-down Procedure

If a marine mammal was first observed within the 180-dB safety zone of the 640 in^3 or 320 in^3 arrays, the airguns were immediately powered down to a single source airgun (40 in^3). If the marine mammal was still traveling toward or entering the reduced safety zone, a shut-down was administered. After a complete shut-down, clearance of the applicable safety zone (640 in^3 or 320 in^3 arrays) had to be visually confirmed before any ramp-up procedures began. The term *clearance* indicates a specific time (15 min for pinnipeds or 30 min for cetaceans) where the safety zone is monitored and no marine mammals are observed or when a marine mammal is observed to have left the applicable safety zone of the full array (640 in^3 or 320 in^3 arrays). However, if the airguns were off for more than 10 min, a 30-min watch was required to clear the 180 dB safety zone prior to ramp-up.

4.2.2.4 Protocol during Poor Visibility Conditions

If the full 180 dB safety zone was not visible during foggy or low light conditions, the airguns did not start a ramp-up procedure from a full shut-down. However, if one or more airguns were operational before nightfall or before the onset of poor visibility conditions, airguns remained operational and ramp-up procedures were initiated. Even though the safety zone was not visible, the operating airgun(s) potentially alerted marine mammals to the presence of airgun activity.

4.2.3 Mitigation Measures for Subsistence Activities

No seismic surveys with airgun operations were conducted inside of the barrier islands before July 25 or outside of the barrier islands after August 25, following the CAA. In accordance with the CAA, PSOs on source vessels communicated with the Deadhorse Communication and Call Center (Com-Center) beginning on August 15. From July 25 through August 25, PSOs on each source vessel attempted communication four times per day (at 0000, 0600, 1200, 1800 Alaska Daylight Time [AKDT]), but not all calls received a response. After August 25, only one source vessel (typically the *Resolution*) was required to call the Com-Center because all three source vessels were close to each other inside of the barrier islands. Information reported to the Com-Center included PSO name, vessel name, vessel position, vessel speed, and planned activity for the next 6 hr.

Additional monitoring was conducted on three occasions outside of the barrier islands after August 25 in accordance with the terms of the NMFS-issued IHA (on August 29, September 1, and September 5). These surveys were conducted by one PSO onboard the *Kimberlin Cat*. The purpose of these surveys was to monitor for bowhead whales and to verify propagation of airgun sounds from inside of the barrier islands using a dipping hydrophone (results of acoustic recordings are included in the acoustic report; see Appendix A). If four or more cow/calf bowhead whale pairs were sighted within the 120 dB safety zone, the PSO was to implement appropriate mitigation measures (i.e., power-down or shut-down).

4.3 Monitoring Procedures

The visual monitoring protocol implemented during the seismic survey was designed in accordance with the provisions of the NMFS-issued IHA and USFWS-issued LOA (see Appendices B and C, respectively). Prior to the start of the survey, all PSOs participated in a 2-day PSO training course to familiarize them with the monitoring protocol, the local marine mammals, and operational procedures. In addition, all PSOs working on the seismic source vessels participated in a 2-day BPXA orientation seminar, a 1-day cold water survival training, a 2-day North Slope Training Cooperative training, and a 2-day health, safety, and environment training required by CGGVeritas. During these trainings all survey participants were informed of operational procedures relevant to health, safety, and environment issues.

Thirteen PSOs (twelve vessel-based and one land-based) were present during the entire Simpson Lagoon OBC seismic survey. The land-based PSO served as Lead Observer with responsibilities of managing data, scheduling and filling in as a vessel-based PSO if needed. Two PSOs were available on the source vessels for the majority of the time (95 percent). However, because of personnel and logistic issues, on 2 days only, one PSO was onboard the *Storm Warning*. However, the vessel was not conducting seismic surveys at the time. PSOs were on watch during all vessel activities (24 hr/day), including times when vessels were stationary (at the dock, anchored, or drifting) and during low light/nighttime (i.e., darkness) conditions. Each watch was 12 hr long, but the schedules were staggered to facilitate crew transfers: 0600 and 1800 AKDT for the *Margarita*, 0800 and 2000 for the *Resolution*, and 1000 and 2200 for the *Storm Warning*. While PSOs were on board for the entire 12-hr shift, PSOs observed for a maximum of 4 hr at a time to minimize observer fatigue. Provisions in the NMSF-issued IHA did not require PSOs to maintain watch during nighttime activities, but PSOs remained on-watch to maintain shift schedules and in case a marine mammal could be observed close to the vessel during low light conditions.

PSOs observed from the bridge of the source vessels with an observer’s eye level at approximately 1.4 m ASL on the *Margarita,* approximately 1.6 m ASL on the *Resolution,* and approximately 2.3 m ASL on the *Storm Warning*. The PSOs onboard the *Margarita* and *Storm Warning* had full visibility around the vessel (360 degrees [°]), but given the location of the wheelhouse on the *Resolution*, PSOs onboard this vessel had a limited view directly behind the vessel (approximately 60° was not visible). While on watch, one PSO systematically scanned using the naked eye or Fujinon 7 x 50 reticle binoculars during all vessel activities. During periods of increased activity (i.e., ramp-ups, power-downs, shut-downs), the second PSO typically assisted with observations. Data were recorded when observer effort was increased (two PSOs) and decreased (one PSO), which was taken into account when calculating sighting rates.

PSOs recorded systematic data while on watch, including date, time, seismic state (i.e., seismic or non-seismic periods), water depth, Beaufort sea state, visibility, glare, and sea-ice information, as well as the location, speed, and activity of the vessel. These data were recorded at least every 30 min, or whenever conditions changed significantly. Additional data were recorded whenever marine mammal(s) were sighted. These data included date, time, species, total number of individuals, number of juveniles, bearing relative to vessel's heading, direction of movement relative to the vessel, distance from the vessel, behavior when sighted, whether the animal was in water or hauled out on ice or land, behavioral pace, reaction to the vessel, vessel position, bottom depth, presence of non-project vessels, and the time that mitigation measures were requested (if necessary). Calls to the Com-Centers were made every 6 hr and documented in a logbook. Data were later entered into a Microsoft Access database and manually checked by comparing the handwritten datasheets to the database. During data processing, further quality control exercises were conducted to resolve or eliminate inconsistent data entry, wrong combination of codes, or other factors. Section 5 provides more details on the analyses performed.

5.0 MARINE MAMMAL MONITORING ANALYSES AND RESULTS

This section describes the results of the marine mammal mitigation and monitoring program implemented during BPXA's 2012 Simpson Lagoon OBC seismic survey. It includes a description of post-field data processing and analysis. An estimation of the numbers of marine mammals potentially affected during the seismic survey operations is also provided.

5.1 Data Analyses

To distinguish potential differences in behavior and distribution of marine mammals with project activity, data were categorized as seismic or non-seismic. Seismic periods included the data collected from source vessels while airguns were operating. This included ramp-ups, power-downs, and the periods when only a single source (40 in^3) was active. Non-seismic periods included all data that were obtained when the airguns were deactivated, such as during transit or while at anchor.

Environmental factors including high sea conditions, poor visibility, glare, and PSO experience can make marine mammal identification difficult, and pinniped species could not always be identified to species with a high level of certainty. Distinguishing ringed seals from spotted seals is especially difficult; therefore, this survey included a ringed/spotted seal category. PSOs were trained in the importance of labeling an animal as "unidentified" if PSOs were unsure of species identification. The category "unidentified seal" was used if the PSO was confident that the animal was a spotted, ringed, or bearded seal. The category "unidentified pinniped" was used if the PSO was unsure whether the animal was a seal or walrus. However, given that walrus sightings in the project area are rare, these sightings were likely seals. For analysis purposes, all sightings were labeled pinnipeds, regardless of whether they were identified to the species level. Due to the sparsity of the data, statistical analyses were not justified to compare sighting rates, environmental conditions, or behavioral state of the animal.

5.1.1 Estimated Number of Exposures

For purposes of the IHA, NMFS assumes that any marine mammal potentially exposed to airgun pulses with received sound levels of greater than or equal to 160 dB re 1µPa (rms) may have been disturbed. In this survey, the distances of the marine mammal sightings to the source vessels were always within or close to the 160 dB safety zone radius of the 640 in^3 airgun array. Given the limited number of marine mammal sightings (a total of 45 sightings from all three source vessels), it is not reasonable to calculate species densities that are corrected for availability and perception bias and to use those numbers to estimate the number of exposures to seismic sounds. Instead of using densities, as was done for other seismic surveys (Richardson 1998; Funk et al. 2008), the procedure described below was used to obtain a minimum and maximum estimated number of marine mammal exposures to greater than or equal to 160 dB re 1µPa (rms) for comparison with the numbers as estimated in the NMFS-issued IHA. The results of these calculations are presented in Section 5.4.

The estimated *minimum* number of marine mammals that could have been exposed to seismic sounds of 160 dB or more is assumed to be the number of animals actually observed within the applicable safety zone radii during airgun operations. In this survey, all pinnipeds that were sighted when airguns were operational were within the 160 dB safety zone. While some marine mammals (mostly pinnipeds) may have been missed by the PSOs, all three source vessels operated close to each other, thereby increasing the possibility that the same animal was observed by more than one PSO. Given the possibility that an animal was observed by PSOs on different source vessels, using the actual number of sightings is representative of the minimum number of animals potentially exposed, even when missed sightings are considered.

For an estimated *maximum* number of pinnipeds exposed, sighting rates were calculated per hour effort (number of sightings/hr) for the period when airguns were non-operational (i.e., non-seismic period). Under the assumption that the non-seismic sighting rate was representative for an undisturbed animal, it was used to calculate the number of sightings that could have occurred during the daylight period when airguns were operating based on the seismic effort in hours. While no pinniped sightings were recorded during darkness, it is possible that seals may have been present when at least one airgun (40 in^3) was operational (i.e., seismic activity) in darkness. Therefore, the daylight sighting rate (i.e., number of sightings/hr) for on-watch, non-seismic periods (i.e., no airguns were operational) was used to calculate the number of animals expected to be present during darkness, based on the seismic effort in darkness. Separate sighting rates were calculated for each source vessel, and the maximum non-seismic sighting rate was used for the maximum exposure calculations.

Cetacean maximum exposure rates were harder to calculate given that no cetacean sightings occurred during the survey. In the absence of direct data, a multiplier of 4 was used to estimate the number of animals that may have been missed (see IHA application for more details: BPXA 2012). This multiplier was used with the assumption that at least one whale may have been missed by PSOs during the survey.

5.2 Results

5.2.1 Observer Effort

The seismic survey started on July 26 with the lay-out of the first cable patch, and seismic data acquisition started on July 29. In the period between July 29 and August 2, the seismic source vessels were engaged in SSV measurements and conducted airgun tests to optimize data acquisition methods. Seismic data acquisition ended on September 7. PSOs were onboard source vessels during seismic and non-seismic periods beginning July 29 through September 7 (see Table 5.1). On-watch periods consist of times when the vessel was moving (i.e., in transit, line shooting, or off-line shooting) while off-watch periods include times when the vessels were stationary (i.e., drifting, anchored or at the dock). During the seismic survey, PSOs were on the *Margarita* for a total of 956 hr, with seismic activity occurring 31.9 percent of the time, on the *Resolution* for a total of 987 hr, with seismic activity occurring 36.7 percent the time, and on the *Storm Warning* for 929 hr, with seismic activity occurring 4.6 percent of the time (see Table 5.2). PSO effort was considered "on-watch" when the vessel was active in transit or airguns were operational. By this definition, all seismic activity occurred on-watch. PSO effort was considered "off-watch" when the vessel was stationary (anchored, drifting, or docked). All off-watch effort was during non-seismic activity (no airguns operating).

Table 5.1 Number of hours for watch effort (on- or off-watch) for the *Margarita*, *Resolution,* and *Storm Warning* during the Simpson Lagoon OBC Seismic Survey (July 29 to September 7).

	Margarita	*Resolution*	*Storm Warning*
On-watch	624.68	715.19	149.60
Off-watch	331.62	272.06	779.17
Total	**956.30**	**987.25**	**928.77**

Table 5.2 Number of hours for seismic state (seismic or non-seismic periods) for the *Margarita*, *Resolution,* and *Storm Warning* during the Simpson Lagoon OBC Seismic Survey (July 29 to September 7). Airguns did not fire (no seismic activity) while PSOs were off-watch.

	On-watch Seismic	On-watch Non-Seismic
Margarita	305.47	319.21
Resolution	362.18	353.01
Storm Warning	42.79	106.81
Total	**710.44**	**779.03**

The majority of time spent on-watch was during daylight hours: 92, 94, and 97 percent for the *Margarita*, *Resolution*, and *Storm Warning*, respectively (see Figures 5.1 and 5.2). From July 29 to August 15, there was no darkness, i.e., low light conditions that limited reliable detection of marine mammals. After mid-August, periods of darkness increased to a maximum of 8 hr on September 7, the last full day of seismic data acquisition. PSOs were on-watch for all daylight hours. Although nighttime observations were not required by the IHA, PSOs maintained watch throughout the night to accommodate crew change schedules and because there was limited space on the vessels to retreat to other than the bridge.

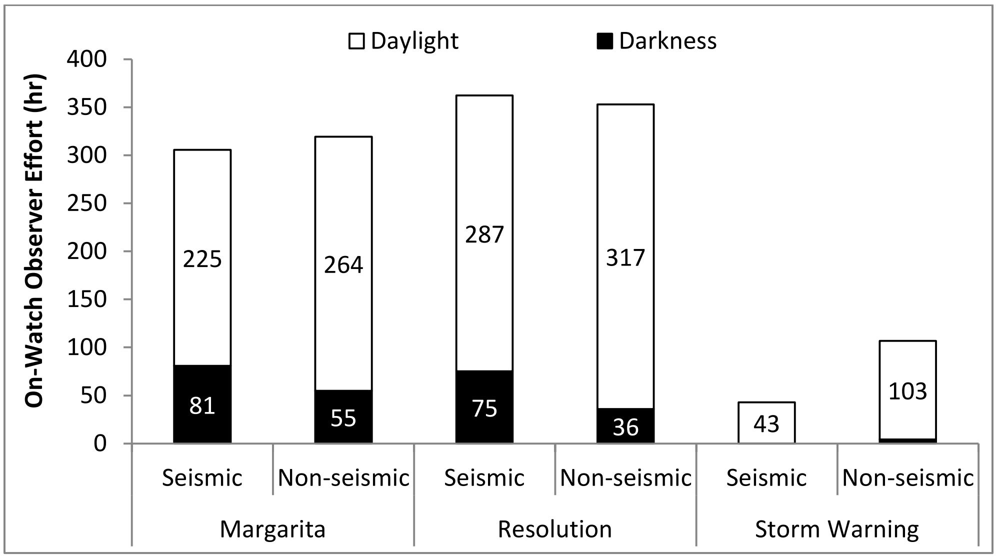

Figure 5.1 Total on-watch observer effort (hours) based on lighting conditions (daylight or darkness) for the *Margarita*, *Resolution,* and *Storm Warning* during the Simpson Lagoon OBC seismic survey.

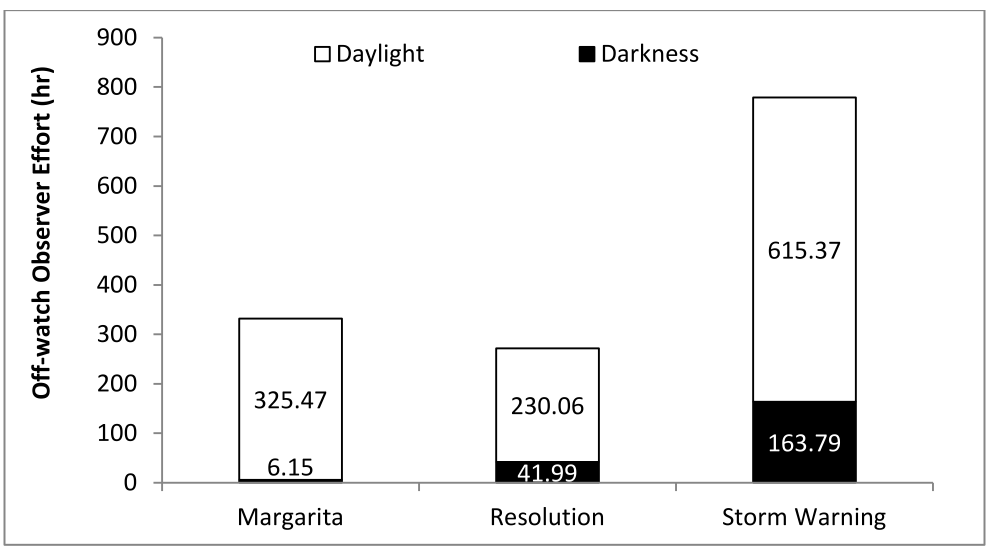

Figure 5.2 Total off-watch observer effort (hours) based on light condition (daylight or darkness) for the *Margarita*, *Resolution,* and *Storm Warning* during the Simpson Lagoon OBS seismic survey.

The ability to detect marine mammals depends largely on environmental conditions, such as sea state and visibility. During the seismic survey, the Beaufort (Bf) sea state, which represents a combination of wind speed and wave height, ranged from 0 to 7. As the Bf sea state increases, it becomes harder to sight marine mammals. Eighty-two percent of the total hours (on- and off-effort combined) occurred when the Bf sea state was between 0 and 3, which corresponds to wind speeds between 0 and 19 km/hr (1 to 10 kt) and wave heights of 0 to 1 ft (see Figure 5.3). In addition, 89 percent of on-watch seismic survey activity occurred during Bf sea state of 0 to 3. This suggests that few marine mammals may have been missed based on sea state.

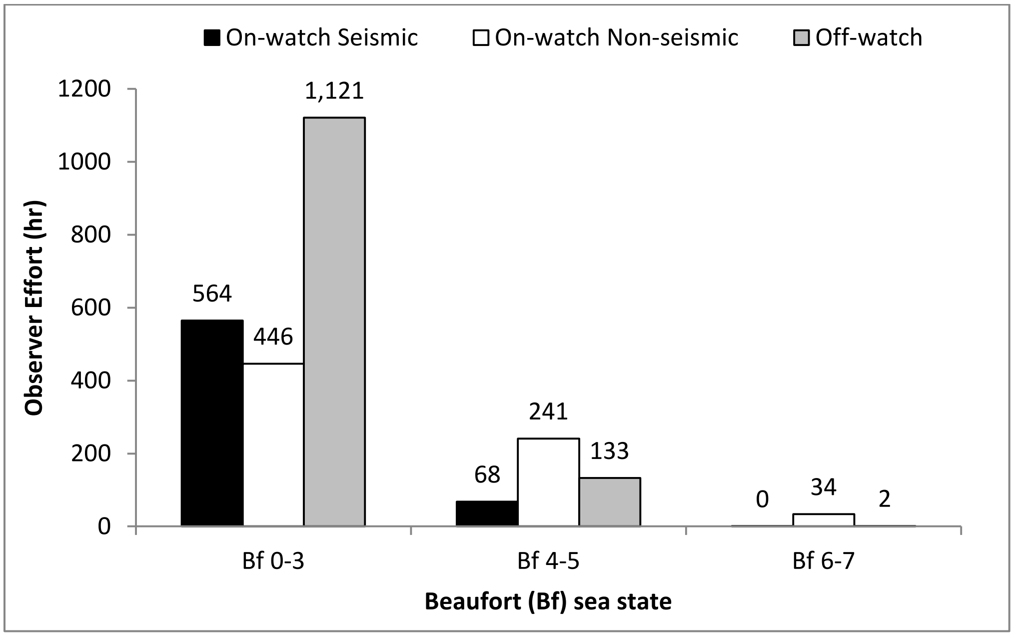

Figure 5.3 Total observer effort (hours) by Beaufort (Bf) sea state for the *Margarita*, *Resolution*, and *Storm Warning*. Hours from all three source vessels were combined. All off-watch hours occurred when airguns were non-operational (i.e., non-seismic).

Visibility is another factor used to determine marine mammal sightability. Visibility may be reduced by fog, rain, or darkness, and may also be limited by obstruction by objects such as floating ice. There was very little ice visible from the project area. All ice that was visible was never closer than 2 km to the source vessels. Fog, rain, and darkness did limit visibility during the seismic survey. However, visibility was greater than 1 km for 88 percent of observer effort and greater than 10 km (i.e., full visibility) for 37 percent of observer effort (see Figure 5.4). While visibility was less than 1 km for 295 hr, only 15 percent (45 hr) occurred when airguns were firing (seismic periods). Additionally, while some marine mammals may not have been observed because of limited visibility, at least one 40 in^3 airgun was operational prior to decreasing visibility. Under this assumption, marine mammals were alerted to the presence of seismic activity.

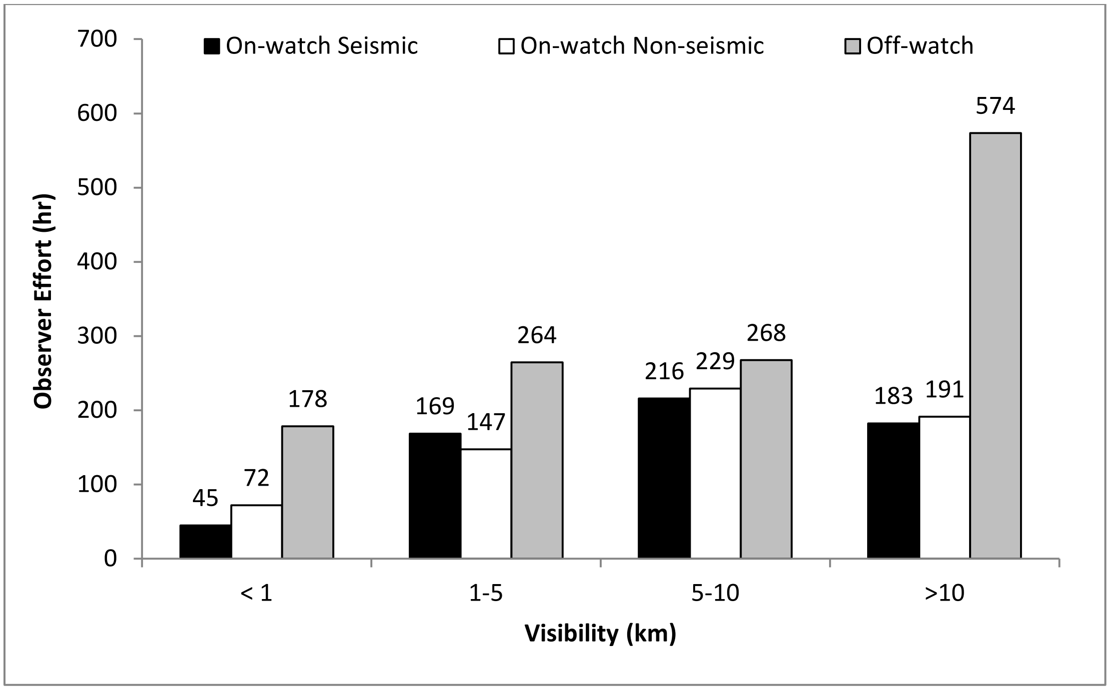

Figure 5.4 Total observer effort (hours) during seismic activity by visibility (km) for the *Margarita*, *Resolution*, and *Storm Warning* during the Simpson Lagoon seismic survey. Hours from all three source vessels were combined. All off-watch effort occurred when airguns were non-operational (i.e., non-seismic activity).

5.2.2 Marine Mammal Sightings

5.2.2.1 Species

There were no cetacean sightings during the entirety of the project. An estimated 47 pinnipeds were seen in 45 sightings within the seismic survey area from July 29 to September 7 from the three seismic source vessels (see Figure 5.5 and Table 5.4). Figures 5.6, 5.7, and 5.8 show the location of all pinniped sightings from the *Margarita*, *Resolution*, and *Storm Warning* during the Simpson Lagoon OBC seismic survey. All pinniped sightings in Figures 5.6, 5.7, and 5.8 are shown regardless of watch status (i.e., on- or off-watch) or seismic state (i.e., seismic or non-seismic periods).

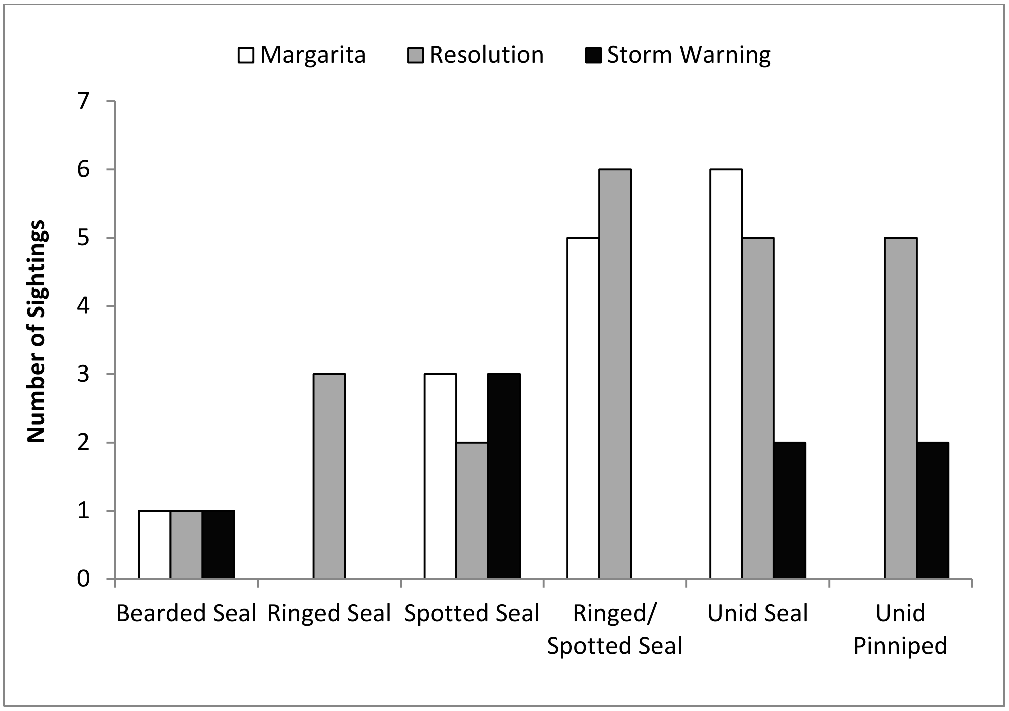

Figure 5.5 Number of pinniped sightings by species for the *Margarita*, *Resolution*, and *Storm Warning*. All sightings are combined regardless of watch effort (i.e., on- or off-watch) or seismic state (i.e., seismic or non-seismic periods).

Table 5.3 Number of sightings (number of individual animals) of pinnipeds from the *Margarita*, *Resolution*, and *Storm Warning* during the Simpson Lagoon OBC seismic survey (July 29 to September 7). On-watch included times when the vessel was active (transiting, line shooting, off-line shooting). Off-watch included times when the vessels were stationary (at anchor, drifting, or docked).

Species	**ON-WATCH**				**OFF-WATCH**			
	Margarita	***Resolution***	***Storm Warning***	**Total**	***Margarita***	***Resolution***	***Storm Warning***	**Total**
Ringed seal	5 (5)	3 (3)	0	*8 (8)*	0	0	0	*0*
Spotted seal	2 (2)	1 (1)	0	*3 (3)*	1 (1)	1 (1)	3 (3)	*5 (5)*
Ringed/Spotted seal	0	5 (5)	0	*5 (5)*	0	1 (1)	0	*1 (1)*
Bearded seal	1 (1)	1 (1)	0	*2 (2)*	0	0	1 (1)	*1 (1)*
Unidentified seal	5 (5)	5 (5)	1 (1)	*11 (11)*	1 (1)	0	1 (1)	*1 (1)*
Unidentified pinniped	0	5 (6)	0	*5 (6)*	0	0	2 (3)	*3 (4)*
Total pinnipeds	***13 (13)***	***20 (21)***	***1 (1)***	***34 (35)***	***2 (2)***	***2 (2)***	***7 (8)***	***11 (12)***

Table 5.4 Brief summary of pinniped sightings and behavior relative to seismic state (seismic or non-seismic) from the *Margarita*, *Resolution*, and *Storm Warning* during the Simpson Lagoon OBC seismic survey (July 29 to September 7).

Date	Species	Number of Animals	Estimated Distance (m)	Depth (m)	Airgun Activity	Behavior
7/27/12	Ringed/Spotted seal	1	20	5.3	Non-seismic	Animal observed swimming; looked at vessel
7/27/12	Ringed seal	1	30	1.5	Non-seismic	Animal observed swimming; looked at vessel
7/30/12	Ringed/Spotted seal	1	250	13.8	Seismic	Animal observed swimming before diving
7/30/12	Ringed/Spotted seal	1	300	14	Seismic	Animal looked at the vessel, then swam away
7/31/12	Unidentified pinniped	1	40	2.4	Non-seismic	Head of animal was observed before sinking
7/31/12	Ringed/Spotted seal	1	100	1.1	Non-seismic	Animal looked at vessel before diving
8/3/12	Unidentified seal	1	600	1.9	Non-seismic	Animal observed swimming before diving
8/3/12	Ringed/Spotted seal	1	70	10.5	Seismic	Animal looked at vessel before sinking
8/4/12	Spotted seal	1	40	2.1	Non-seismic	Animal looked at vessel before sinking
8/4/12	Ringed/Spotted seal	1	80	1.4	Non-seismic	Animal observed swimming before diving
8/4/12	Unidentified pinniped	2	1000	1.5	Non-seismic	Head of animal was observed before sinking
8/5/12	Unidentified pinniped	1	50	5.5	Non-seismic	Animal observed swimming before diving
8/5/12	Spotted seal	1	40	2	Non-seismic	Animal observed feeding before diving
8/6/12	Unidentified seal	1	150	12	Non-seismic	Animal observed swimming before diving
8/6/12	Unidentified pinniped	2	40	3	Non-seismic	Animal observed swimming; looked at vessel
8/6/12	Unidentified pinniped	1	120	8.5	Seismic	Animal observed swimming before diving
8/11/12	Ringed/Spotted seal	1	75	11.9	Seismic	Animal observed swimming; looked at vessel
8/11/12	Ringed/Spotted seal	1	100	7.1	Seismic	Animal observed swimming; looked at vessel
8/11/12	Spotted seal	1	100	11.9	Non-seismic	Animal observed swimming; looked at vessel
8/11/12	Ringed/Spotted seal	1	800	4	Non-seismic	Animal observed swimming before diving
8/11/12	Unidentified seal	1	80	5.2	Non-seismic	Animal looked at vessel before sinking
8/11/12	Spotted seal	1	20	1.5	Non-seismic	Animal observed swimming before diving

Table 5.4 Brief summary of pinniped sightings and behavior relative to seismic state (seismic or non-seismic) from the *Margarita*, *Resolution*, and *Storm Warning* during the Simpson Lagoon OBC seismic survey (July 29 to September 7).

8/12/12	Bearded seal	1	100	7.8	Seismic	Animal looked at vessel before diving
8/12/12	Unidentified seal	1	130	6.5	Non-seismic	Animal looked at vessel before diving
8/13/12	Bearded seal	1	40	6.4	Non-seismic	Animal observed swimming before diving
8/13/12	Unidentified seal	1	400	11.8	Seismic	Animal observed swimming
8/13/12	Unidentified Seal	1	500	13	Seismic	Animal looked at vessel before diving
8/13/12	Unidentified pinniped	1	300	3	Non-seismic	Animal observed swimming
8/16/12	Unidentified seal	1	140	9.7	Non-seismic	Animal looked at vessel before sinking
8/17/12	Ringed seal	1	50	2.4	Seismic	Animal looked at vessel before diving
8/18/12	Ringed seal	1	450	13.2	Seismic	Animal observed swimming
8/20/12	Unidentified pinniped	1	50	14.2	Seismic	Animal observed swimming
8/24/12	Unidentified seal	1	250	2.4	Non-seismic	Animal observed swimming; looked at vessel
8/25/12	Unidentified seal	1	200	2	Non-seismic	Animal looked at vessel before sinking
8/26/12	Bearded seal	1	160	2.2	Non-seismic	Animal observed swimming
8/26/12	Unidentified seal	1	225	3.3	Seismic	Animal observed swimming
8/27/12	Unidentified seal	1	300	2.9	Non-seismic	Animal observed swimming
8/28/12	Unidentified seal	1	600	2.4	Seismic	Animal observed swimming
8/29/12	Spotted seal	1	150	1.8	Seismic	Animal observed swimming before diving
8/30/12	Spotted seal	1	80	2.4	Non-seismic	Animal observed swimming before diving
8/31/12	Spotted seal	1	30	1.5	Non-seismic	Animal observed swimming; looked at vessel
9/5/12	Spotted seal	1	95	1.3	Non-seismic	Animal observed swimming
9/6/12	Ringed/Spotted seal	1	15	2.5	Non-seismic	Animal observed swimming; looked at vessel

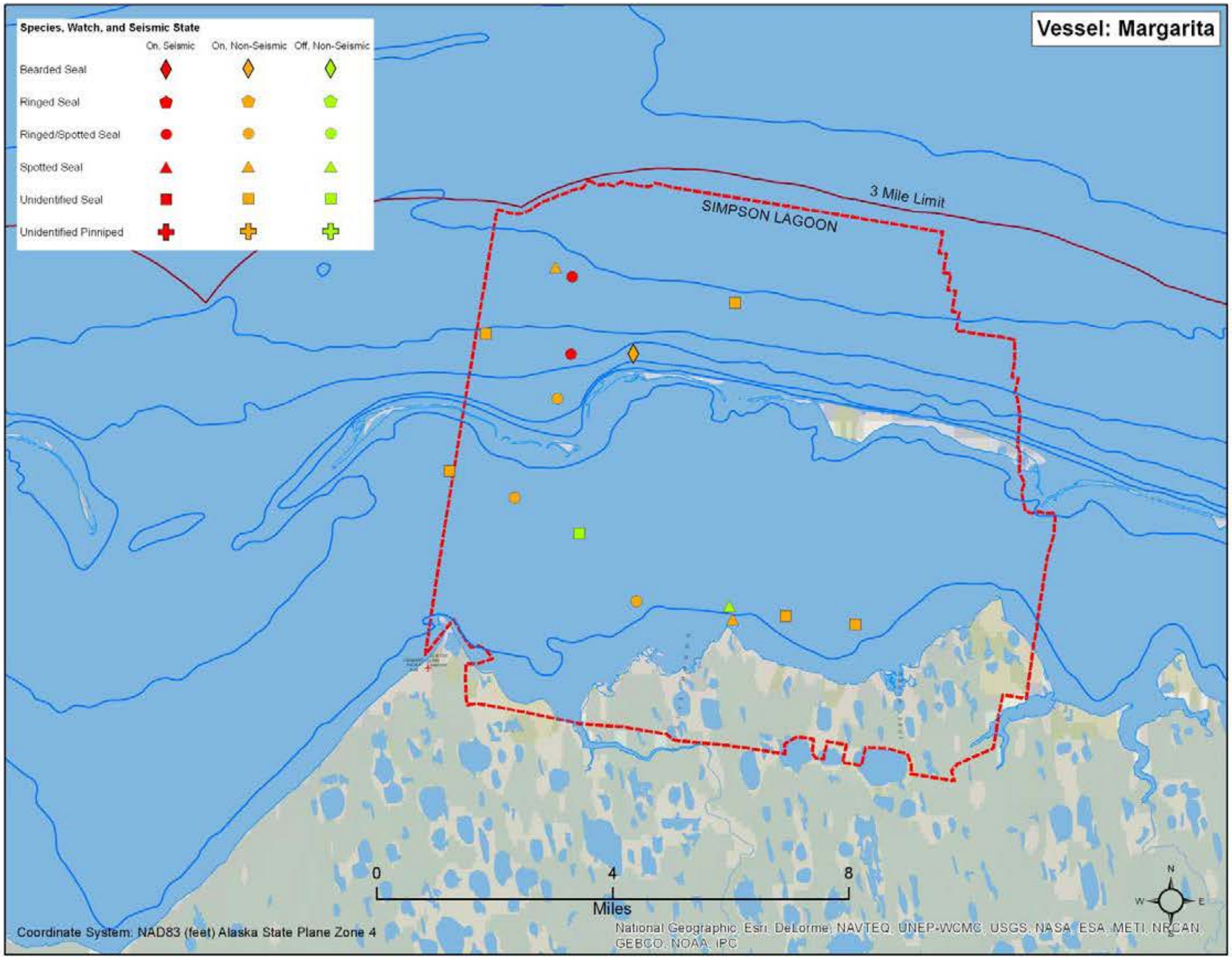

Figure 5.6 Location of pinniped sightings from the *Margarita* during the seismic survey from July 29 to September 7. The post-survey area (red dashed line) is included for reference.

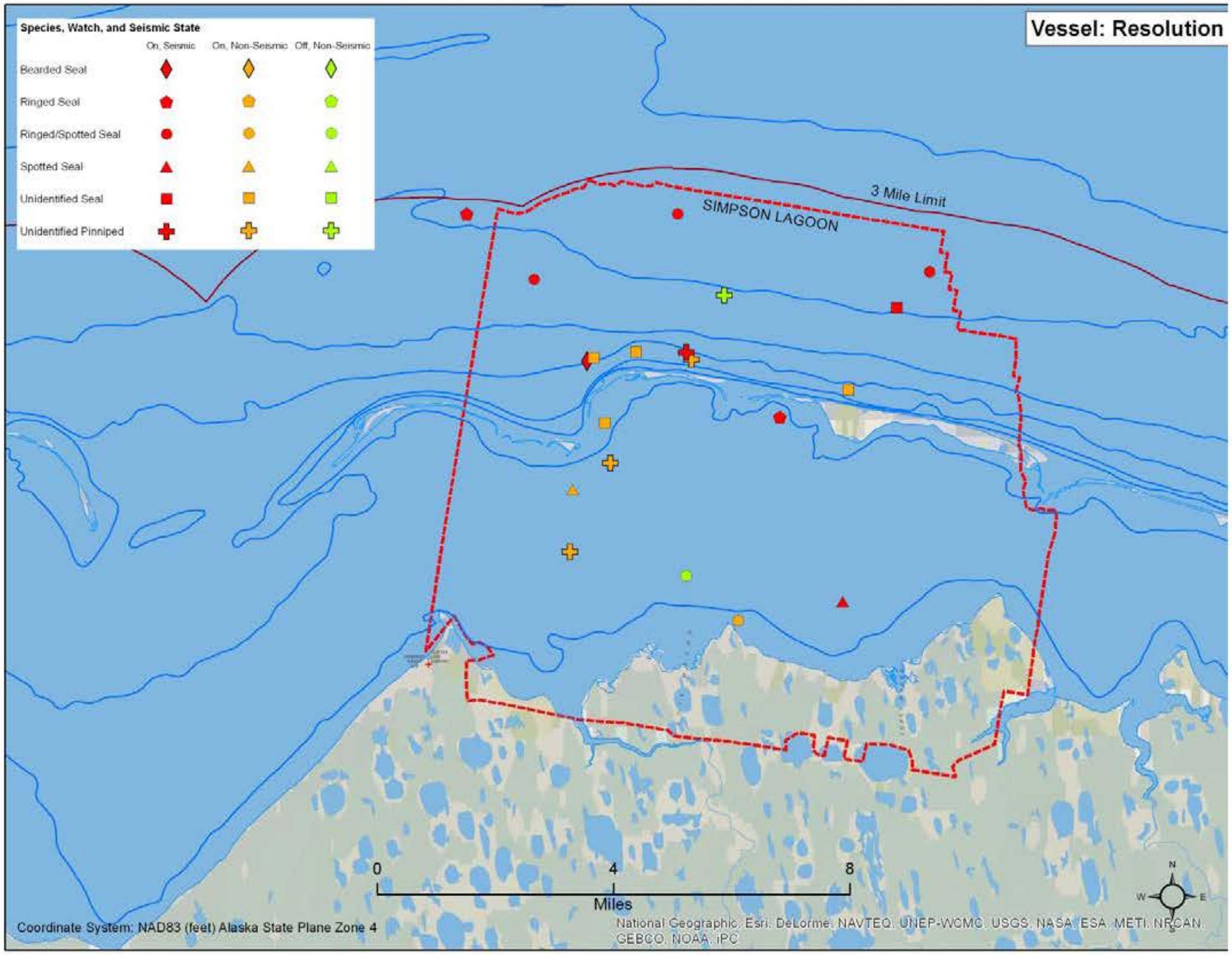

Figure 5.7 Distribution of pinniped sightings from the *Resolution* during the seismic survey from July 29 to September 7. The post-survey area (red dashed line) is included for reference.

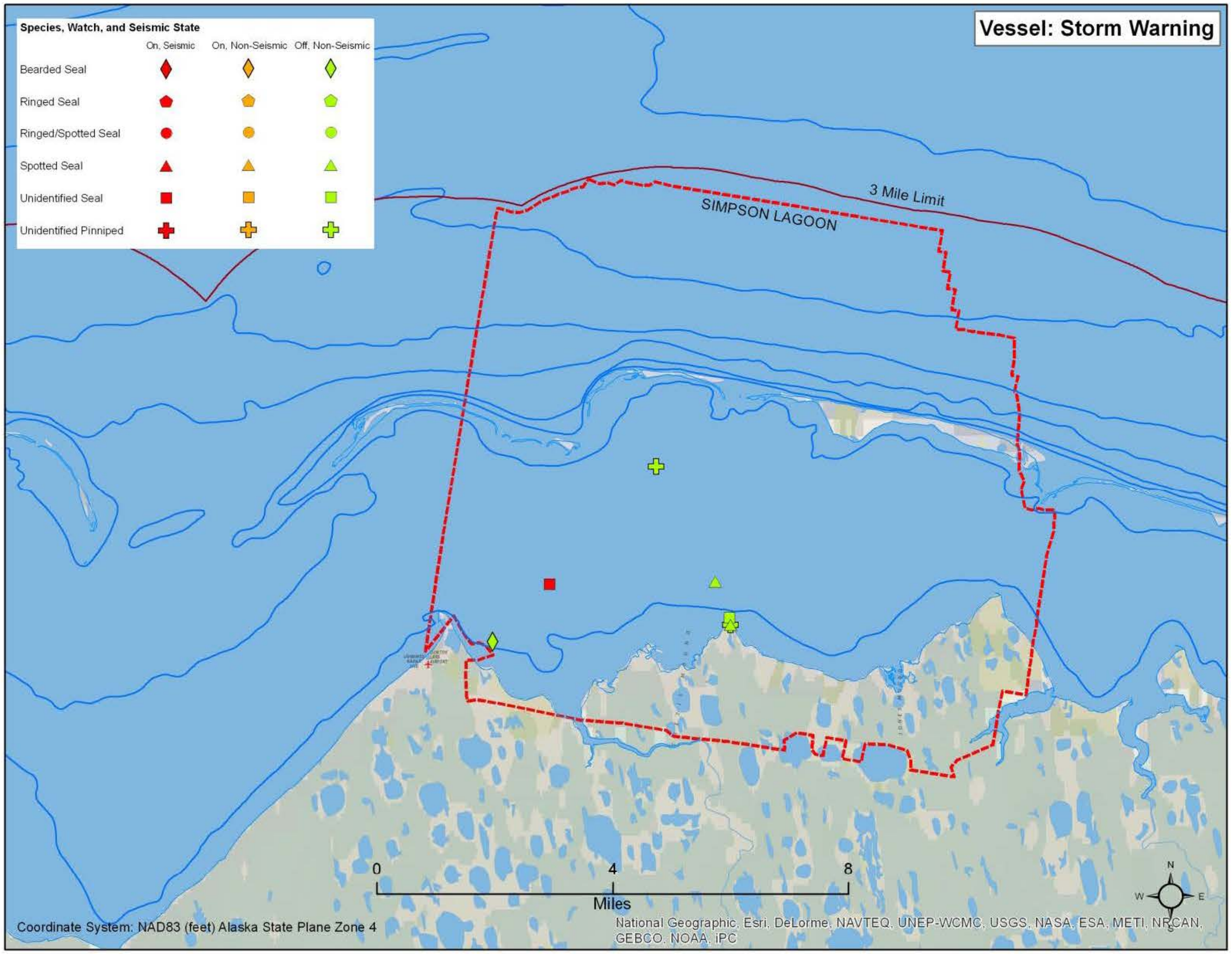

Figure 5.8 Distribution of pinniped sightings from the *Storm Warning* during the seismic survey from July 29 to September 7. The post-survey area (red dashed line) is included for reference.

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5.2.2.2 Sighting Details

Figure 5.9 shows the number of pinniped sightings recorded for each source vessel during seismic (with operating airguns) and non-seismic (without operating airguns) periods. There were more sightings during on-watch periods on the *Margarita* and *Resolution* (seismic and non-seismic periods combined), but the *Storm Warning* showed an opposite trend, with more sightings off-watch. However, it should be noted that the *Storm Warning* spent 84 percent of the total observer effort off-watch, which explains the low number of on-watch number sightings.

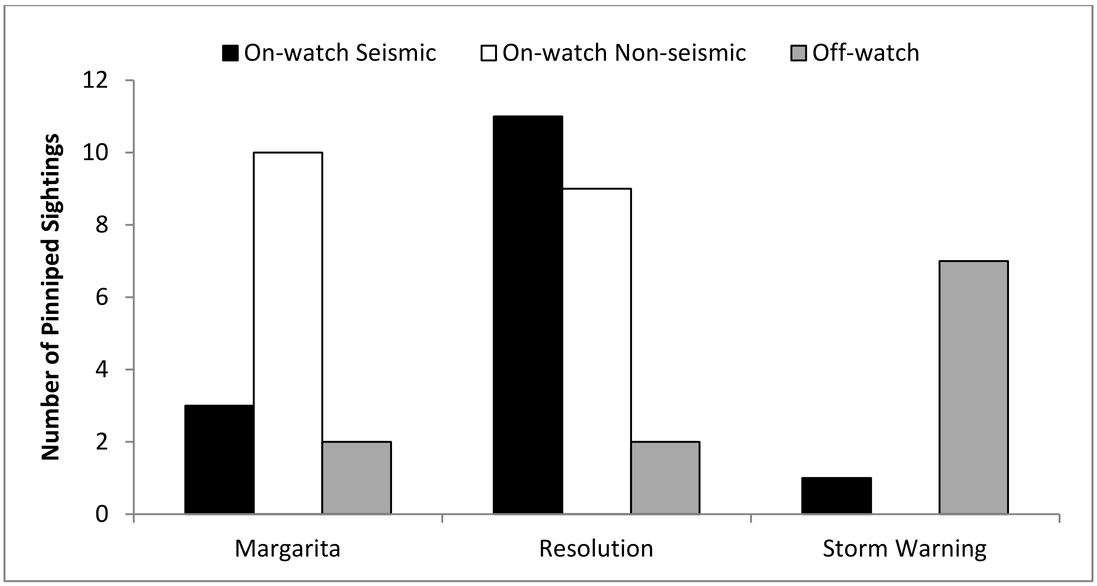

Figure 5.9 Total number of pinniped sightings observed from the *Margarita*, *Resolution*, and *Storm Warning* during the Simpson Lagoon OBC seismic survey (July 29 to September 7). Seismic activity included times when at least one 40 in^3 airgun was operational, while non-seismic activity included times when all of the airguns were nonoperational. All off-watch effort occurred when airguns were nonoperational (non-seismic).

Sighting rates (i.e., the number of PSO sightings per unit of effort) are summarized in Table 5.5 and shown in Figure 5.10. The sighting rates were calculated by dividing the total number of combined on-watch pinniped sightings on each vessel with the on-watch observer effort for seismic or non-seismic periods. Sighting rates were calculated without taking re-sights into consideration, whether the animal was spotted more than once during an encounter or possibly sighted by PSOs on other vessels.

Table 5.5 On-watch sighting rates for pinnipeds during seismic and non-seismic periods. Ramp-up and power-down efforts are included in the seismic category. All on-watch pinniped sightings were combined regardless of whether they were identified to species or not.

	Observation Effort On-watch (h)	PINNIPEDS	
		Number of Sightings	Sighting Rate (number/hr)
Margarita			
Seismic	306	3	0.010
Non-seismic	319	10	0.031
Resolution			
Seismic	363	11	0.030
Non-seismic	353	9	0.026
Storm Warning			
Seismic	43	1	0.023
Non-seismic	107	0	0.0

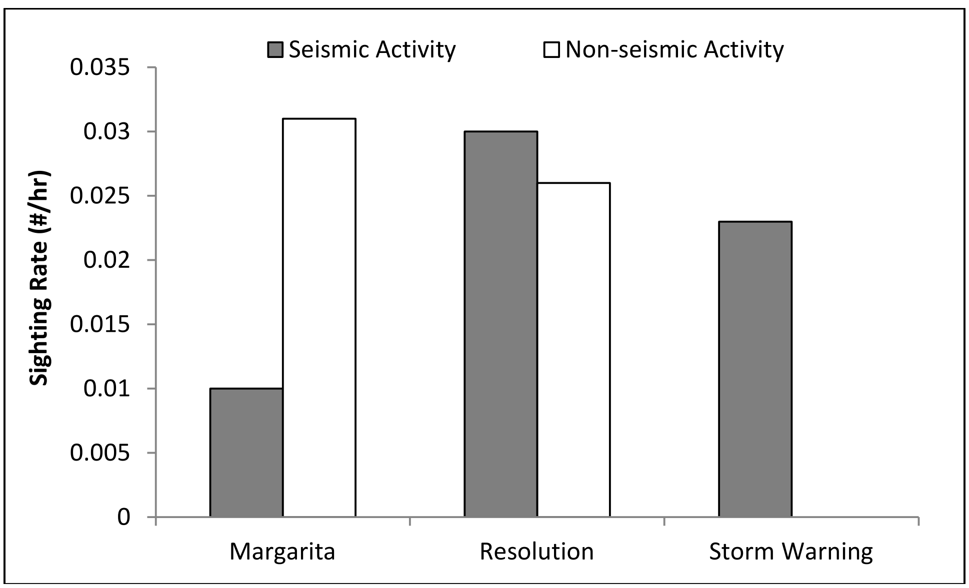

Figure 5.10 Sighting rate for pinniped observations during on-watch observer effort. All pinnipeds were combined regardless of whether they were identified to species or not. Seismic activity included times when at least one 40-in^3 airgun was operational while non-seismic activity included times when all of the airguns were nonoperational.

Because the sighting rate takes observer effort into account, a comparison between source vessels can be made. The three source vessels showed different sighting patterns. A higher sighting rate during non-seismic periods occurred on the *Margarita*, while the number of sightings remained similar on the *Resolution* regardless of the status of airgun operations (seismic or non-seismic periods). The pattern for the *Storm Warning* shows that the sighting rate was higher during seismic periods, but this number is based on only one sighting and, therefore, cannot be considered a good representation.

While Bf sea state ranged from 0 to 7 during the entire survey, the majority of on-watch sightings occurred between Bf sea states of 0 and 2 (see Figure 5.11). No on-watch sightings occurred above Bf sea state of 5. As expected, there were more sightings with less wind resulting in calmer waters (i.e., lower Bf sea state).

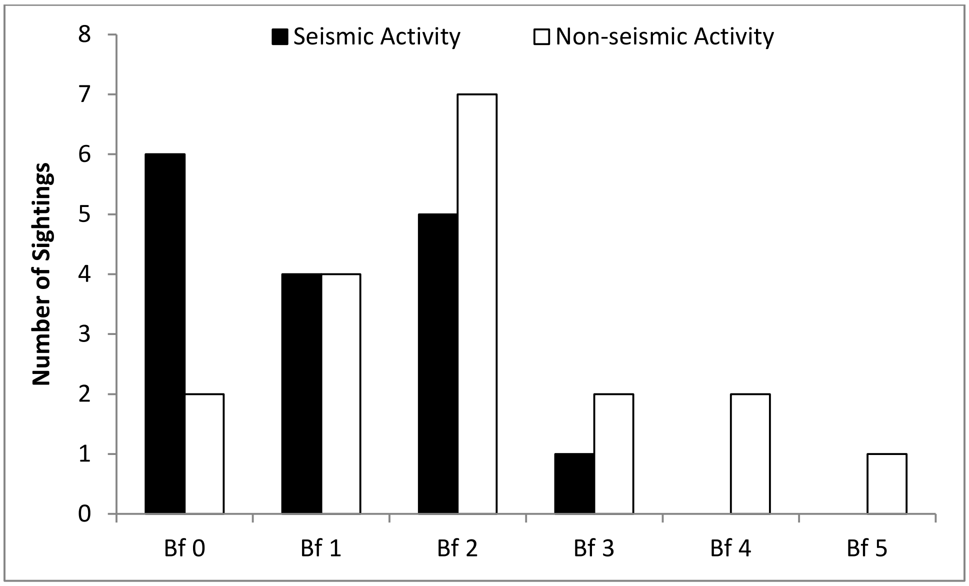

Figure 5.11 Number of on-watch pinniped sightings by Beaufort (Bf) sea state for all three source vessels combined (*Margarita*, *Resolution*, and *Storm Warning*). All pinniped sightings were combined regardless of whether they were identified to species or not.

Table 5.6 On-watch pinniped sighting rates by Beaufort (Bf) sea state for seismic and non-seismic periods. Data from all three source vessels (*Margarita*, *Resolution*, and *Storm Warning*) are combined. All pinniped sightings were combined regardless of whether they were identified to species or not.

	On-watch Effort (hr)	Number of Sightings	Sighting Rate (number/hr)
Seismic Activity			
Bf 0–1	440	10	0.023
Bf 2–3	332	6	0.018
Bf 4–5	0.3	0	0
Non-seismic Activity			
Bf 0–1	277	6	0.022
Bf 2–3	269	9	0.034
Bf 4–5	34	3	0.088

During on-watch observer effort, visibility was greater than 1 km for 91 percent of the time, and full visibility (i.e., greater than 10 km) occurred 30 percent of the time (see Table 5.7). During seismic periods, sighting rates were highest for visibility between 5 and 9 km, followed by visibility greater than 10 km. During non-seismic, on-watch periods, the highest sighting rate occurred with full visibility (i.e., 10 km).

Table 5.7 On-watch sighting rates for pinnipeds during different visibility conditions from the *Margarita*, *Resolution*, and *Storm Warning*, combined. All pinniped sightings were combined regardless of whether they were identified to species or not.

	On-watch Effort (hr)	Number of Sightings	Sighting Rate (number/hr)
Seismic Activity			
<1 km	45	0	0
≥1–<5 km	169	3	0.018
5–9 km	216	10	0.046
≥10 km	183	5	0.027
Non-seismic Activity			
<1 km	72	0	0
≥1–<5 km	147	3	0.020
5–9 km	229	5	0.022
≥10 km	191	8	0.042

There were few re-sights of pinnipeds during the seismic survey (n = 8 out of 45 sightings). While the lack of re-sights is likely attributable to the cryptic nature of seals (i.e., quick encounters at the surface), PSOs were trained to focus on monitoring the entire exclusion zones rather than concentrating on re-sights of individual animals. When re-sights were recorded, it was because the animal was sighted closer to the vessel. Therefore, the distance for the initial sighting and closest point of approach (CPA) were the same for the majority (82 percent) of sightings. All pinniped sightings were within a 20- to 1,200-m (66- to 3,937-ft) distance from the vessel. Figure 5.12 shows the number of on-watch pinniped sightings by CPA distance based on seismic state (i.e., seismic or non-seismic) for all three source vessels combined.

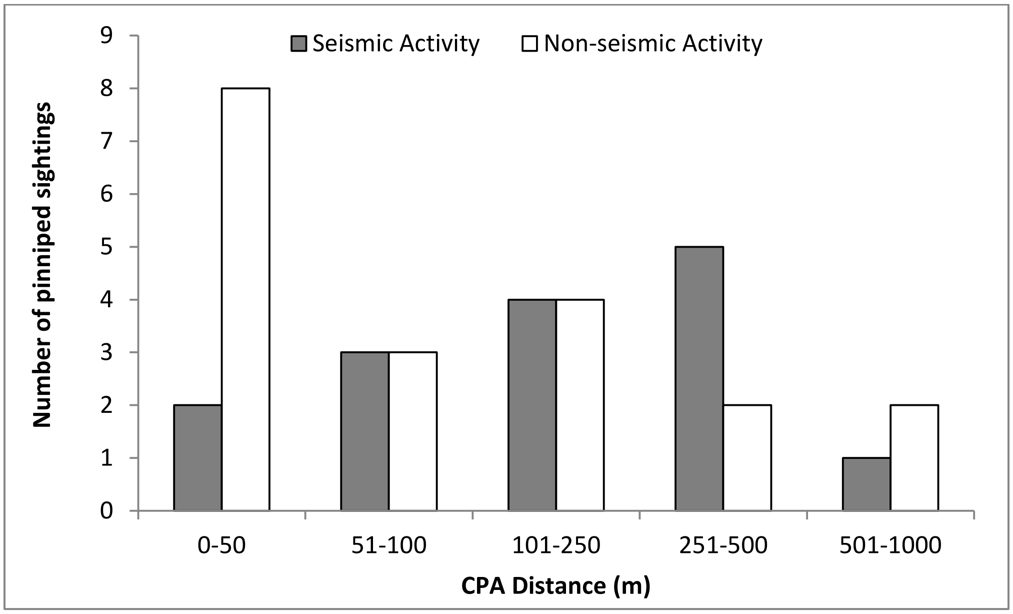

Figure 5.12 Number of on-watch pinniped sightings by distance to closest point of approach (CPA) during seismic and non-seismic periods. Data from all three source vessels (*Margarita*, *Resolution*, and *Storm Warning*) were combined. All pinnipeds sightings were combined regardless of whether they were identified to species or not.

5.2.2.3 Behavior

Pinniped behaviors were categorized as "swimming" (51 percent of sightings), "looking" (40 percent), "diving" (6.5 percent), "sinking" (2 percent), and "feeding" (0.5 percent). The PSOs onboard the *Storm Warning* observed the only incident of feeding behavior, where a fish was observed in the mouth of a spotted seal. PSOs did not observe reactions by pinnipeds to any vessel activity during 71 percent of the sightings (on- and off-watch combined). During the 29 percent of sightings with a behavioral response note, the only reaction observed by PSOs was "looking," which meant the seal looked at the vessel at some point during the encounter.

5.3 Mitigation Measures Implemented

During the Simpson Lagoon OBC seismic survey, a total of five shut-downs (11 percent of sightings), three power-downs (7 percent of sightings), and five delayed ramp-ups (11 percent of sightings) occurred for pinnipeds. Two additional shut-downs occurred for polar bear sightings (see USFWS 90-day report for details). A delayed ramp-up occurred when a marine mammal was observed during the 30-min clearance period. If ramp-up was initiated (i.e., at least one airgun was operational) when a marine mammal was sighted, reducing the number of airguns was considered a power-down (one 40 in^3 airgun) or shut-down (no airguns were operational). Given the small size of the bridge on all source vessels, PSOs, gunners, and captains were in constant communication and all PSO mitigation requests were implemented as soon as possible (within seconds). Four of the five shut-downs occurred when an animal was sighted at distances of 50 m, 50 m, 75 m and 150 m from the seismic source. The remaining shut-down occurred for an animal that was sighted at a distance of 500 m from the seismic source; while this was outside of the 190-dB safety zone, the animal was headed toward the safety zone (following procedure defined in Section 4.2.2.3). All three power-downs occurred when an animal was observed approaching the safety zone.

5.4 Estimated Numbers of Exposures

The IHA requires estimates of the amount and nature of potential harassment of marine mammals. Meaningful estimates of the number of marine mammals potentially exposed to seismic sounds are difficult to obtain for several reasons: (i) the relationship between numbers of marine mammals observed and the number actually present is uncertain; (ii) the distance to which a received sound level exceeds a specific criterion such as 190 and 180 dB re 1 μPa (rms) is variable, especially in the shallow-water environment in which the Simpson Lagoon seismic survey took place (Burgess and Greene 1999; Caldwell and Dragoset 2000; Greene 1998; Greene et al. 1998; Tolstoy et al. 2004a, 2004b); (iii) 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, 2004b); and (iv) the most appropriate criteria for harassment from exposure to sounds are uncertain and presumed to vary among different species and situations.

The method used to estimate the number of marine mammals exposed to airgun sounds strong enough that they might have caused a disturbance or other potential impacts is explained in Section 4.1. It includes: (i) minimum estimates based on the number of marine mammals observed by PSOs at distances corresponding to estimated received sound levels of greater than or equal to 160 dB; and (ii) maximum estimates based on pinniped sighting rates obtained during this survey and extrapolated to periods of low light conditions. The actual number of individuals exposed to, and potentially affected by, airgun sounds likely was between the minimum and maximum estimates provided in the following sections and summarized in Table 5.8.

5.4.1 Minimum Estimate

The actual number of marine mammals observed within the applicable safety zone radii of the seismic vessels (*Margarita*, *Resolution*, and *Storm Warning*) during airgun operations provides a minimum estimate of the number potentially affected by seismic sounds. This is likely a conservative approach (i.e., an underestimate of the actual number potentially affected) because it is unlikely that PSOs were able to detect all marine mammals. During daylight, animals are missed if they are below the surface. At other times, even if the animal surfaced near the vessel, they may be missed because of limited visibility (e.g., fog, twilight, darkness), high Bf sea state, glare, or other factors limiting detectability. In particular, detecting seals can be challenging because seals often spend limited time at the surface, quickly surfacing and sinking within seconds.

Cetacean exposures – There were no sightings (zero individuals) of cetaceans by PSOs on source vessels. Therefore, the minimum number of cetacean exposures to sound levels greater than or equal to 160 dB is zero.

Pinniped exposures – Six individual seals were observed by PSOs onboard the *Margarita* while airguns were operational, eleven individual animals were observed by PSOs onboard the *Resolution* while airguns were operational, and one seal was observed by PSOs onboard the

Storm Warning while airguns were operational. Therefore, there was a minimal number of 18 pinniped exposures to sound levels greater than or equal to 160 dB. It is possible that a few pinnipeds in the area were missed by PSOs or that the animals were beneath the surface of the water when a source vessel was nearby. However, as stated earlier, all three source vessels worked in a small geographic area, increasing the possibility that the same animal was observed and counted by more than one PSO on a different source vessel. Because both of these numbers are small, it is reasonable to assume that the number of animals missed and double-counted offset each other, making the minimum number of animals observed a good representation of pinnipeds in the survey area.

5.4.2 Maximum Estimate

Cetacean exposures – The sighting rate for cetaceans during daylight seismic periods is zero. Typically, the assumption is that the daylight, non-seismic sighting rate is representative for seismic daylight and nighttime hours. Therefore, the maximum number of potential pinniped exposures to sound levels greater than or equal to 160 dB is the number of sightings one might have expected in the absence of airguns. Therefore, the maximum number of potential cetacean exposures to sound levels greater than or equal to 160 dB is the number of sightings one might have expected in the absence of airguns. However, since no cetacean sightings occurred during this survey, this calculation is not appropriate.

In the absence of survey data, it is assumed that at least one cetacean may have been missed during the survey. To estimate the maximum number of cetacean exposures, a multiplier of 4 was used (see IHA application; BPXA 2012). Therefore, the maximum estimate for potential cetacean exposures is 4 individuals. This is a reasonable estimate given that the survey was designed to minimize interactions with cetaceans. No seismic operations occurred inside of the barrier islands prior to July 25 to minimize potential interactions with beluga whales. No seismic operations occurred outside of the barrier islands after August 25 to minimize interactions with bowhead whales as they are undertook their fall migration. In addition, regular conversations with Com-Centers ensured that no project activities interfered with any subsistence activities (see Section 5.5).

Pinniped exposures – The pinniped sighting rate during periods when airguns were operating was 0.024 sightings/hr and 0.014 sightings/hr when airguns were turned off (i.e, non-seismic). Typically, the assumption is that the non-seismic pinniped sighting rate is representative for seismic daylight and nighttime hours. Therefore, the maximum number of potential pinniped exposures to sound levels greater than or equal to 160 dB is the number of sightings one might have expected in the absence of airguns. However, during this survey, the sighting rate for non-seismic activity was lower than the sighting rate during seismic activity for all three vessels. To be conservative, the highest sighting rate per vessel (0.03 sightings/hr on the *Storm Warning*) was used to calculate the maximum number of animals potentially exposed to airgun sounds levels greater than or equal to 160 dB.

Total daylight seismic effort = 271.4 hr (*Margarita*) + 341.2 hr (*Resolution*) + 41.6 hr (*Storm Warning*) = 653.9 hr
Total nighttime seismic effort = 23.6.5 hr (*Margarita*) + 21.8 hr (*Resolution*) + 1.3 hr (*Storm Warning*) = 46.7 hr
Maximum number of potential exposures = (653.9 hr + 46.7 hr) x 0.03 sightings/hr = 21

Table 5.8 Summary of minimum and estimated maximum number of potential marine mammal exposures to airgun sounds of greater than or equal to 160 dB from the *Margarita*, *Resolution*, and *Storm Warning* during the Simpson Lagoon OBC seismic survey. The estimated number of pinniped and cetacean exposures listed in the IHA is provided for comparison.

Species	Estimated Exposures to Sound Pressure Levels ≥160 dB		Estimated Exposures to Sound Pressure Levels ≥160 dB as Listed in IHA
	Minimum	Maximum	
Cetaceans	0	4	98
Pinnipeds	18	21	151
Total	***18***	***25***	***278***

In summary, the maximum number of pinnipeds potentially exposed to sound levels greater than or equal to 160 dB based on actual sightings was 14 percent of the estimated numbers. The difference between the estimated minimum and maximum pinniped exposures is small (three animals) because there were few nighttime seismic periods (a total of 23 hr). Four pinnipeds were sighted within the estimated radius for the 190-dB safety zone, which triggered immediate shut-downs. The potential cetacean exposure to sound pressure levels greater than or equal to 160 dB was 4 percent of estimated numbers. However, this is likely an overestimate because the survey was designed to minimize potential interactions with cetaceans, in particular, bowhead whales.

5.5 Communication Centers

There was no indication that any of the above-mentioned activities affected subsistence resources of the local communities. The Simpson Lagoon OBC seismic survey started prior to the fall bowhead whale migration and the corresponding subsistence hunt by the village of Nuiqsut. Calls to the Deadhorse Com-Center were required to begin on August 1 and continued through the end of the seismic survey. During the majority of the survey, at least one Inupiat-speaking PSO was onboard each source vessel, and calls were made every 6 hr. Each call to the Com-Center provided the position (latitude and longitude) of each of the source vessels and a brief description of planned activities. In accordance with the CAA, no airgun activities occurred outside of the barrier islands after August 25, the first day of the whaling season. One PSO monitored outside the barrier islands for the presence of four or more cow/calf bowhead pairs for approximately 10 hr over 3 days (August 29, September 1, and September 5). No sightings occurred during this monitoring effort.

REFERENCES

AEWC (Alaska Eskimo Whaling Commission). 2012. *2012 Open Water Season Programmatic Conflict Avoidance Agreement*. Signed by BPXA 4 June 2012.

Allen, B.M., and R.P. Angliss. 2012. *Alaska marine mammal stock assessments, 2011*. NOAA Technical Memorandum NMFS-AFSC-234. National Marine Fisheries Service, Seattle, Washington.

BPXA (BP Exploration Alaska Inc.). 2011. *Incidental Harassment Authorization request for the non-lethal harassment of whales and seals during the Simpson Lagoon OBC seismic survey, Beaufort Sea, Alaska, 2012*. Submitted to National Marine Fisheries Service, Silver Spring, Maryland.

BPXA (BP Exploration Alaska Inc.). 2012. *Supplemental information submission to Incidental Harassment Authorization request for the non-lethal harassment of whales and seals during the Simpson Lagoon OBC Seismic Survey, Beaufort Sea, Alaska, 2012*. Submitted to National Marine Fisheries Service, Silver Spring, Maryland.

Burgess, W.C., and C.R. Greene, Jr. 1999. Physical acoustics measurements. Pages 3-1 to 3-63 *In* W.J. Richardson (ed.). *Marine mammal and acoustical monitoring of Western Geophysical's open-water seismic program in the Alaskan Beaufort Sea, 1998*. LGL Rep. TA22303. Prepared by LGL Ltd., King City, Ontario, and Greeneridge Sciences Inc., Santa Barbara, California, for Western Geophysical, Houston, Texas, and National Marine Fisheries Service, Anchorage, Alaska, and Silver Spring, Maryland.

Caldwell, J., and W. Dragoset. 2000. A brief overview of seismic air-gun arrays. *The Leading Edge* 19:898-902.

Christie, K., C. Lyons, and W.R. Koski. 2010. Beaufort Sea aerial monitoring program. Chapter 7 *In*: Funk, D.W, D.S. Ireland, R. Rodrigues, and W.R. Koski (eds.). 2010. *Joint monitoring program in the Chukchi and Beaufort seas, open water seasons, 2006–2008*. LGL Alaska Report P1050-3. Report from LGL Alaska Research Associates, Inc., LGL Ltd., Greeneridge Sciences, Inc., and JASCO Research, Ltd., for Shell Offshore, Inc. and Other Industry Contributors, and National Marine Fisheries Service, and U.S. Fish and Wildlife Service.

Funk, D., D. Hannay, D. Ireland, R. Rodrigues, and W. Koski, eds. 2008. *Marine mammal monitoring and mitigation during open water seismic exploration by Shell Offshore Inc. in the Chukchi and Beaufort seas, July-November 2007: 90-day report*. LGL Alaska Report P969-1. Report from LGL Alaska Research Associates, Inc., LGL Ltd., and JASCO Research Ltd. for Shell Offshore Inc, National Marine Fisheries Service, and U.S. Fish and Wildlife Service.

Greene, C.R., Jr. 1997. Physical acoustics measurements. Chapter 3 *In*: W.J. Richardson (ed.), 1997. *Northstar Marine Mammal Marine Monitoring Program, 1996. Marine mammal and acoustical monitoring of a seismic program in the Alaskan Beaufort Sea*. LGL Report TA2121-2. Rep. from LGL Ltd., King City, Ontario, and Greeneridge Sciences Inc., Santa Barbara, California, for BP Exploration (Alaska) Inc., Anchorage, Alaska, and National Marine Fisheries Service, Anchorage, Alaska, and Silver Spring, Maryland.

Greene, C.R., Jr., R. Norman, and J.S. Hanna. 1998. Physical acoustics measurements. Chapter 3 *In:* W.J. Richardson (ed.), *Marine mammal and acoustical monitoring of BP Exploration (Alaska)'s open-water seismic program in the Alaskan Beaufort Sea, 1997*. LGL Report TA2150-3. Report from LGL Ltd., King City, Ontario, and Greeneridge Sciences Inc., Santa

Barbara, California, for BP Exploration (Alaska) Inc., Anchorage, Alaska, and National Marine Fisheries Service, Anchorage, Alaska, and Silver Spring, Maryland.

Greene, C.R., Jr., and W.J. Richardson. 1988. Characteristics of marine seismic survey sounds in the Beaufort Sea. *Journal of the Acoustical Society of America* 83(6):2,246-2,254.

Harris, R.E., G.W. Miller, and W.J. Richardson. 2001. Seal responses to airgun sounds during summer seismic surveys in the Alaskan Beaufort Sea. *Marine Mammal Science* 17(4):795-812.

Kelly B.P, O.H. Badajos, M. Kunnasranta , J.R. Moran, M. Martinez-Bakker, D. Wartzok, and P. Boveng. 2010. Seasonal home ranges and fidelity to breeding sites among ringed seals. *Polar Biology* 33:1095-1109.

Lowry, L.F., K.J. Frost, R. Davis, D.P. DeMaster, and R.S. Suydam. 1998. Movements and behavior of satellite-tagged spotted seals (*Phoca largha*) in the Bering and Chukchi Seas. *Polar Biology* 19(4):221-230.

Miller, G.W., V.D. Moulton, R.A. Davis, M. Holst, P. Millman, A. MacGillivray, and D. Hannay. 2005. Monitoring seismic effects on marine mammals—southeastern Beaufort Sea, 2001-2002. Pages 511-542 *In*: S.L. Armsworthy, P.J. Cranford, and K. Lee (eds.). *Offshore oil and gas environmental effects monitoring: approaches and technologies*. Battelle Press, Columbus, Ohio.

Moore, S.E., and H.P. Huntington. 2008. Arctic marine mammals and climate change: Impacts and resilience. *Ecological Applications* 18:S157-S165.

Moulton, V.D., W.J. Richardson, T.L. McDonald, R.E. Elliott, and M.T. Williams. 2002. Factors influencing local abundance and haulout behavior of ringed seals (*Phoca hispida*) on landfast ice of the Alaskan Beaufort Sea. *Canadian Journal of Zoology* 80(11):1,900-1,917.Reeves, R.R., B.S. Stewart, P.J. Clapham, and Powell, J.A. 2002. *National Audubon Society guide to marine mammals of the world*. Alfred A Knopf, Inc. and Chanticleer Press, Inc., New York.

Richardson, W.J., ed. 1998. *Marine mammal and acoustical monitoring of BP Exploration (Alaska)'s open-water seismic program in the Alaskan Beaufort Sea, 1997*. LGL Report TA2150-3. Report from LGL Ltd., King City, Ontario, and Greeneridge Sciences Inc., Santa Barbara, California, for BP Exploration (Alaska) Inc., Anchorage, Alaska, and National Marine Fisheries Service., Anchorage, Alaska, and Silver Spring, Maryland.

Richardson, W.J., D.H. Thomson, C.R. Greene, Jr., and C.I. Malme. 1995. *Marine mammals and noise*. Academic Press, San Diego, California.

Richardson, W.J., G.W. Miller, and C.R. Greene, Jr. 1999. Displacement of migrating bowhead whales by sounds from seismic surveys in shallow waters of the Beaufort Sea. *Journal of the Acoustical Society of America* 106(4, Part 2):2,281.

Shelden, K.E.W., and J.A. Mocklin, eds. 2012. *Bowhead Whale Feeding Ecology Study (BOWFEST) in the western Beaufort Sea, 2011 Annual Report*. OCS Study BOEM 2012-077. Bureau of Ocean Energy Management, Anchorage, Alaska.

Tolstoy, M., J. Diebold, S. Webb, D. Bohnenstiehl, and E. Chapp. 2004a. Acoustic calibration measurements. Chapter 3 *In:* W.J. Richardson (ed.). *Marine mammal and acoustic monitoring during Lamont-Doherty Earth Observatory's acoustic calibration study in the northern Gulf of Mexico, 2003*. Revised. LGL Report TA2822-12. Prepared by LGL Ltd., King City, Ontario, for Lamont-Doherty Earth Observatory, Palisades, New York, and NMFS, Silver Spring, Maryland

Tolstoy, M., J.B. Diebold, S.C. Webb, D.R. Bohenstiehl, E. Chapp, R.C. Holmes, and M. Rawson. 2004b. Broadband calibration of R/V *Ewing* seismic sources. *Geophysical Research Letters* 31:L14310. doi:*17* 10.1029/2004GL020234

Warner, G., and S. Hipsey. 2011. *Acoustic noise modeling of BP's 2012 Seismic Program in Simpson Lagoon (Harrison Bay, AK): Version 2.0*. Technical report for OASIS Environmental Inc. by JASCO Applied Sciences.

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Appendix A
JASCO 90 Day Report

Sound Sources Characterization for the 2012 Simpson Lagoon OBC Seismic Survey

90-Day Report

Submitted to:
Bill Streever
BP Exploration (Alaska) Inc.
Contract: PA 15214 under MDA 10416

Authors:
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4 April 2013

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Document Version Control

Version	Date	Name	Change
1.0	31 Oct 2012	H Sneddon	Draft released to client for review.
2.0	6 Dec 2012	H Sneddon / R Racca	Final review, post client comments and author edits. Submitted to client for final review and forwarding to regulators.
3.0	4 April 2013	C McPherson	Final review, all edits incorporated. Released to client.

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Contents

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Executive Summary

In 2012 BP Exploration (Alaska) Inc. conducted an ocean bottom cable (OBC) seismic survey in Simpson Lagoon, Harrison Bay, off the North Slope of Alaska. BP was required to monitor and report underwater sound levels from its survey operations including seismic airgun arrays and vessel activities as stipulated in its Incidental Harassment Authorization (IHA) from NMFS for this work. JASCO Applied Sciences carried out the sound monitoring studies on behalf of BP between July and September 2012. This report provides detailed descriptions of the methods used in the study and the results obtained. An overview of the experimental and analysis methods are given below.

BP's 2012 IHA required measurement of underwater sound levels near certain noise-generating sources. The measurements would be analyzed to determine the distances at which broadband sound levels reached 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). Due to an IHA requirement, distances corresponding to sound levels at 190, 180, 160, and 120 dB re 1 µPa (rms) were also measured.

The OBC survey program was performed with three source vessels: M/V *Margarita,* M/V *Resolution, and* M/V *Storm Warning.* These vessels were equipped with airgun array sources consisting of two 320 in^3 sub-arrays, each with eight 40 in^3 airguns, towed side by side behind the vessel. The M/V *Margarita* and M/V *Resolution* were used outside the barrier islands with either a single sub-array firing at a time or both sub-arrays firing in unison for a total source volume of 640 in^3. Both vessels, and the M/V *Storm Warning* were used inside the barrier islands with only 320 in^3 arrays operating. A single 40 in^3 airgun was used as a mitigation source during turns and on survey line approaches to ensure marine mammals would keep their distance, thus avoiding the risk of being exposed to higher-level sounds from the operational airgun sources (640 and 320 in^3 arrays) when they started operating.

The Sound Source Verification (for seismic sources, which had been previously modeled) and the Sound Source Characterization (for vessel sources) studies were conducted with three autonomous ocean bottom hydrophones, each sampling from two different hydrophones for low and high sensitivity. The acoustic data on each channel were sampled at 96 000 samples per second with 24-bit resolution.

Long-range measurements were conducted using a dipping hydrophone setup provided by JASCO, which consisted of a high-resolution digital recorder in a splash proof housing, programmed to record onto a solid-state drive at 96 000 samples per second and 24-bit resolution. The acoustic sensor, a high sensitivity hydrophone, was connected to the recorder via a ten-meter sealed cable that allowed it to be deployed over the side of a vessel.

Long-term measurements over the entire seismic survey period were conducted using three Autonomous Multichannel Acoustic Recorders (AMARs). Each AMAR recorded one channel continuously at 64 000 samples per second and 24-bit dynamic range using a high sensitivity omnidirectional hydrophone.

The Sound Source Verification studies yielded a complete set of threshold radii for management of the seismic sources both inside and outside the barrier islands. Comparing these to the pre-season modeling results showed that the water sound speed profile (SSP) played a significant role in defining the propagation ranges, and that differences between the originally assumed SSP and what was measured in the field were a prime cause of discrepancies. The definitive ranges to sound level thresholds for the seismic sources used in the OBC survey, which when obtained from measurements were conservatively computed to fit 90% of the observed levels, are given in the tables below for operations outside and inside the barrier islands.

Outside barrier islands: Maximum threshold distances for the mitigation airgun and two airgun arrays. Distances are maximized over direction and environment and are based on the 90th percentile fits.

90% rms SPL Threshold (dB re 1 µPa)	Outside Barrier Islands, 90th Percentile Distance (m)		
	640 in^3	320 in^3	40 in^3
190	516	360	24
180	1386	1134	158*
160	4616	4265	1602
120	14 163	13 313	9221

*Actual maximum range from measurements.

Inside barrier islands: Maximum threshold distances for the mitigation airgun and 320 in^3 airgun array. Distances are maximized over direction and environment and are based on the 90th percentile fits except as noted.

90% rms SPL Threshold (dB re 1 µPa)	Inside Barrier Islands, 90th Percentile Distance (m)	
	320 in^3	40 in^3
190	260	138
180	472	293
160	1545	933
120	5700*	3242

*Based on pre-season model estimate (actual range from measurements was 2528 m).

The long-range acoustic monitoring performed with the dipping hydrophone system did not detect any seismic pulses in the recordings outside the barrier islands at times when seismic sources were active inshore of the islands; this fact was confirmed by analyzing the long-term AMAR recordings at matching times. The long-term measurement data from the AMARs over the duration of the OBC survey showed that the 320 in^3 airgun array sources operating inside the barrier islands never produced received pulse levels outside the islands that exceeded the 120 dB (90% rms SPL) threshold. These results indicate that the acoustic environment of the lagoon drastically attenuates the seismic source pulses as they propagate through the sub-bottom and emerge outside the barrier islands.

1. Introduction

This report presents the results of an underwater acoustic study designed to characterize the sound emissions of seismic sound sources involved in BP's 2012 ocean bottom cable (OBC) seismic survey in Simpson Lagoon, Harrison Bay, Alaska.

Under contract to BP, JASCO Applied Sciences (JASCO) measured underwater sound pressure levels (SPLs) as a function of distance and direction from BP's airgun array sound sources from 29 July to 1 August, 2012 inclusive. The data recorders were retrieved and data downloaded by 1 August, 2012 Alaska Daylight Time (AKDT).

The measured array sound levels were used to verify the pre-season estimates reported in *Acoustic Noise Modeling of BP's 2012 Seismic Program in Simpson Lagoon* (*Harrison Bay, AK*) (Warner and Hipsey 2011).

JASCO was also tasked with additional acoustics measurements to satisfy BP's Incidental Harassment Authorization (IHA), including dipping hydrophone measurements to be conducted after 25 August 2012 and long-term underwater acoustics measurements for the duration of the seismic survey that ended 7 September 2012.

1.1. Summary Goals of the Acoustics Program

JASCO was contracted to address the following acoustics program goals, consistent with the requirements outlined in the IHA:

Airgun Array Sound Source Verification (SSV) and Vessel Characterization (SSC):

- Measure 640 in^3 array, 320 in^3 array, and 40 in^3 mitigation airgun while operating to determine the 190, 180, 160, and 120 dB re 1 µPa (rms) SPL threshold distances in the broadside and endfire directions.
- Measure three vessels used by BP for towing the arrays to determine the 160, 140, and 120 dB re 1 µPa (rms) SPL threshold distances.
- Compare the distances obtained from the measurements with the corresponding distances in the IHA that were based on pre-season modeling.
- Assess threshold distances from acoustic measurements for impulsive and broadband sound levels between 190 and 120 dB re 1 µPa (rms) for each source type.

Monitoring (Dipping Hydrophone):

- Provide an over the side system and associated training to BP's subcontractor HDR Inc., in order that they obtain long-range measurements of seismic pulses outside the barrier islands.
- Analyze data to determine the peak and rms SPL levels received outside the barrier islands at discrete times during the seismic survey after 25 August.

Monitoring (Long-term):

- Measure sound levels inside and outside the barrier islands for up to 50 days over the course of BP's survey.

- Analyze the long-term data to determine the degree to which the barrier islands block seismic survey sound propagation. Compare the peak and rms SPL levels received at each AMAR, two of which were placed outside, and one inside, the barrier islands.
- Examine the contribution of the seismic survey to the acoustic environment over the period of the survey.

2. Methods

2.1. Sound Sources

2.1.1. Sound Source Verifications: Seismic Airguns

Three airgun source configurations were measured for Sound Source Verification: a 640 in^3 array, a 320 in^3 sub-array, and a 40 in^3 mitigation airgun.

The 640 in^3 airgun array consisted of two 320 in^3 sub-arrays (Figure 1), each with eight 40 in^3 airguns, towed side by side behind a survey vessel. The sub-arrays were towed at a 2 m depth outside the barrier islands and at a 1 m depth inside. The 40 in^3 mitigation airgun was a single airgun within one of the sub-arrays.

Figure 1. One of the 320 in^3 sub-arrays which consists of eight 40 in^3 airguns. The 640 in^3 array consisted of two identical 320 in^3 sub-arrays separated horizontally astern of the vessel.

2.1.2. Sound Source Characterizations: Vessels

Three source vessels were used during the seismic survey: the M/V *Resolution* (jet boat), the M/V *Margarita* (propeller boat), and the M/V *Storm Warning* (jet boat) (Figure 2). The *Resolution* and the *Margarita* were used to operate both 640 in^3 and 320 in^3 sources outside the barrier islands, whereas the *Storm Warning* was intended for use inside the islands to tow only the 320 in³ airgun array. All three vessels operated inside the barrier islands, towing 320 in³ airgun arrays.

Figure 2. The three source vessels: (top) *Resolution*; (bottom left) *Margarita*; and (bottom right) *Storm Warning*.

2.2. Equipment

2.2.1. Sound Source Verifications and Characterizations: Ocean Bottom Hydrophones

For the Sound Source Verifications and Characterizations, underwater sound levels were measured with three autonomous ocean bottom hydrophones (OBHs; Figure 3), each sampling from two different hydrophones. The lower sensitivity hydrophones (TC4043 from RESON) have a nominal sensitivity of −201 dB re 1 V/µPa, and the higher sensitivity hydrophones (TC4032 from RESON), −170 dB re 1 V/µPa. The acoustic data were recorded on dual channels onto solid-state drives at 96 000 samples per second with high-resolution 24-bit digital recorders (model 722 from Sound Devices, LLC).

The OBHs in protective frames (Figure 3), weighing in total 32 kg in air, were deployed to the seabed at one end of a 75 m ground line, with a 5 kg weight at the other end. The equipment was retrieved by grappling; no components were left behind.

Figure 3. A JASCO ocean bottom hydrophone (OBH) system on the deck of the deployment vessel, M/V *Cape Fear*. The black housing holds the Sound Devices 722 recorder. The yellow housing is an inactive acoustic release, which was not required for these deployments.

2.2.2. Long-Range Measurements: Dipping Hydrophone

The dipping hydrophone setup provided by JASCO for this study consisted of a high-resolution digital recorder (model 722 from Sound Devices, LLC) in a splash proof housing, programmed to record at 96 000 samples per second, 24-bit resolution, onto a solid-state drive. The acoustic sensor, a high sensitivity hydrophone (TC4032 from RESON), −170 dB re 1 V/µPa, was connected to the recorder via a ten meter extension cable.

The system was designed so that the recorder in a weatherproof housing could be operated from the deck of the vessel, and the hydrophone on extension cable lowered over the side to approximately 7 m below the water surface. The apparatus did not provide instantaneous readings of pulse levels; it recorded full waveform acoustic data that were later processed by JASCO offsite.

2.2.3. Long-Term Measurements: AMAR

Three Autonomous Multichannel Acoustic Recorders (AMARs) were used to measure the entire seismic survey and ambient levels. Each AMAR recorded one channel continuously at 64 000 samples per second. The recording channel had a 24-bit dynamic range with a spectral noise floor of 20 dB re 1 μPa^2/Hz and a ceiling of 171 dB re 1 µPa. The recorder was fitted with an M8 omnidirectional hydrophone (−165 ± 3 dB re 1 V/µPa sensitivity, GeoSpectrum Technologies Inc.). Data were stored on the internal solid-state flash memory.

The AMARs in protective frames with no flotation components (Figure 4), weighing in total 32 kg in air, were deployed at one end of a 75 m grapple line, with a 5 kg weight at the other end. The equipment was retrieved by grappling; no components were left behind.

Figure 4. An Autonomous Multichannel Acoustic Recorder (AMAR; JASCO Applied Sciences).

2.2.4. Recorder Calibrations

Each recording system was calibrated with a GRAS 42AA pistonphone precision sound source, which generated a 250 Hz reference tone. The equivalent amplitude of the calibration signal in response to the reference tone depends on the type of hydrophone, but approximates 140 dB re 1 µPa. The tone was played directly to the hydrophone sensors with a customized adapter. Calibrations were performed shortly before each deployment and at the end of the active field period for each of the units. The pistonphone reference tone was sampled by the digital recorders and the resulting signal was analyzed to the provide end-to-end system calibration of the hydrophone, amplifiers, and digitization. The pressure sensitivity obtained from the calibration, combined with the manufacturer's sensitivity curves of the hydrophones, was used in the subsequent data analysis to precisely determine the recorded sound levels.

2.3. Data Acquisition

2.3.1. Sound Source Verifications and Characterizations

The test seismic trials program was conducted inside and outside the barrier islands at Simpson Lagoon, Harrison Bay, AK. Figures 5 and 6 show maps of the test areas, the source track lines, and the acoustic monitoring stations. Two track lines were defined for the seismic vessels to follow so their sound levels could be measured: in shallow water inside the barrier islands (2–3 m depth, Track 1) and in deeper water outside the barrier islands (12–14 m depth, Track 2).

Ocean bottom hydrophones (OBHs) deployed outside the barrier islands (A2, B2, and C2 in Figure 5) recorded sound levels while the sources transited Track 2. The OBHs were deployed perpendicular to the track lines extending away from the barrier islands. After measurements for Track 2 were complete, the OBHs were retrieved and redeployed inside the barrier islands for Track 1 measurements (A1, B1, and C1 in Figure 6).

The standard for measurement of vessel noise underwater ANSI/ASA S12.64-2009/Part 1 (ANSI, 2004) is not applicable to the measurement of vessels as part of this SSC due to the shallow water depth of the survey. The use of OBH systems for measuring vessel source levels is the most common technique used in the North Slope offshore environment, and is widely accepted for regulatory verification purposes.

Table 1 lists deployment details for each OBH. Table 2 lists the dates each measured sound source operated and the track lines that they transited.

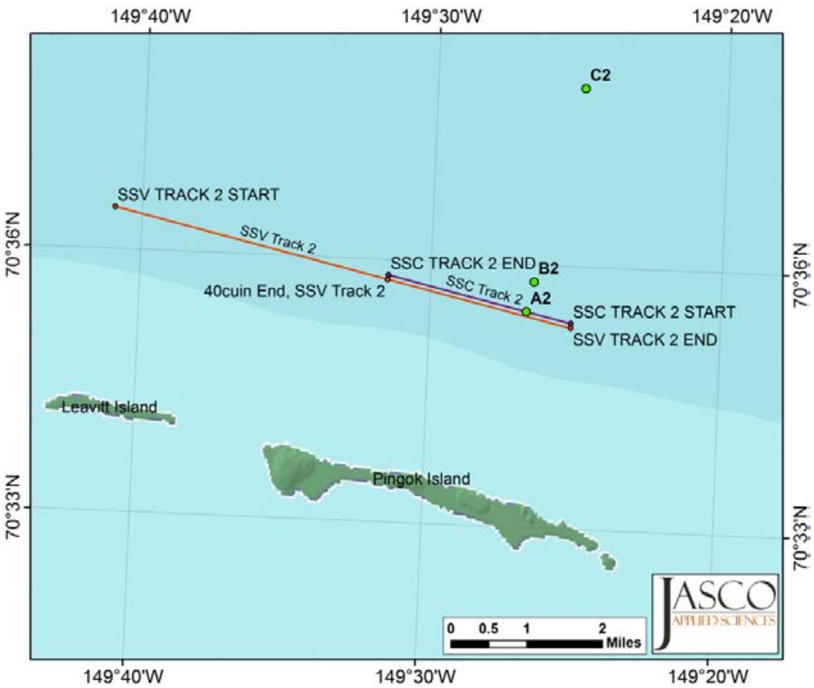


Figure 5. The Track 2 acoustic trial lines outside the Simpson Lagoon barrier islands and the locations of the acoustic recorders (OBHs A2, B2, and C2).

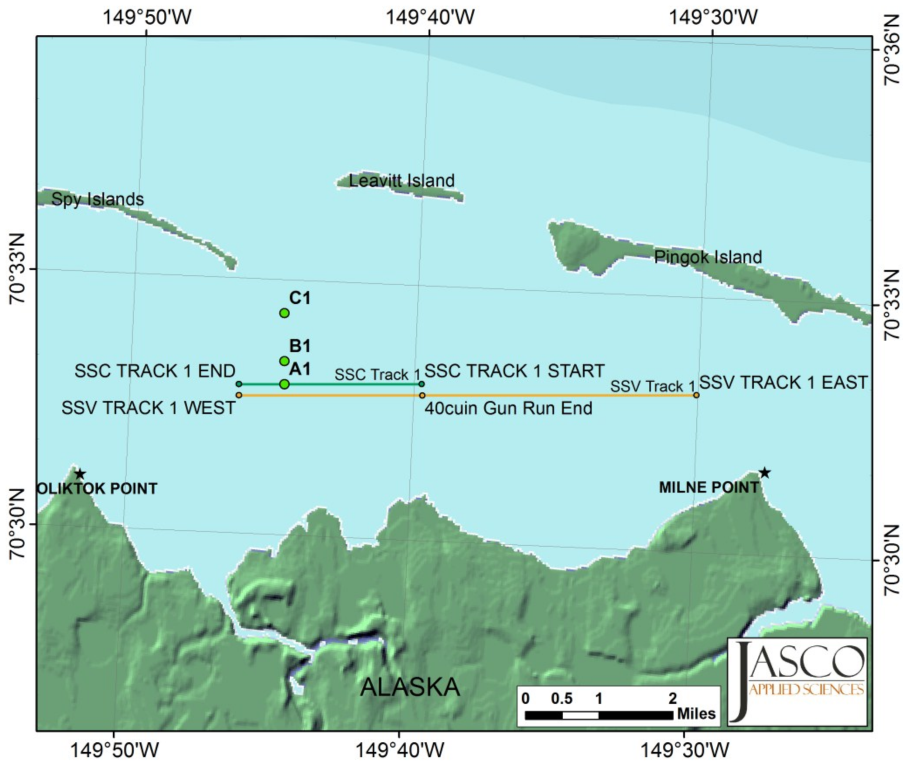


Figure 6. The Track 1 acoustic trial lines inside the Simpson Lagoon barrier islands and the locations of the acoustic recorders (OBHs A1, B1, and C1).

Table 1. Acoustic recorder locations (WGS-84) and deployment and retrieval times (AKDT) for the acoustic measurements at Simpson Lagoon. Water depths were measured at time of deployment.

OBH	Deployment	Retrieval	Latitude	Longitude	Water depth (m)	Range from track (m)	
						SSC	SSV
Outside barrier islands							
A2	29 Jul 03:11	31 Jul 01:09	70°35.472′ N	149°26.683′ W	13	0	100
B2	29 Jul 03:01	31 Jul 02:21	70°35.814′ N	149°26.442′ W	15	650	750
C2	29 Jul 01:37	31 Jul 03:53	70°38.047′ N	149°24.919′ W	18	4900	5000
Inside barrier islands							
A1	31 Jul 04:12	1 Aug 03:07	70°31.782′ N	149°44.562′ W	1.8	0	250
B1	31 Jul 02:46	1 Aug 03:50	70°32.050′ N	149°44.596′ W	1.95	500	750
C1	31 Jul 04:19	1 Aug 04:55	70°32.614′ N	149°44.679′ W	1.8	1550	1800

Table 2. Sound sources monitored during BP's Simpson Lagoon seismic survey, 30 July through 1 August, 2012. Dates and times are in AKDT.

Source	Track	Run	Date	Start	End
Outside barrier islands					
640 in^3 airgun array	SSV Track 2	1	30 Jul	14:01	15:21
320 in^3 airgun array	SSV Track 2	3	29 Jul	16:48	18:30
40 in^3 airgun	SSV Track 2	3	29 Jul	16:48	18:30
M/V *Resolution*	SSC Track 2	2	29 Jul	19:06	19:29
M/V *Margarita*	SSC Track 2	4	30 Jul	02:15	02:32
Inside barrier islands					
320 in^3 airgun array	SSV Track 1	6	31 Jul	13:34	17:12
40 in^3 airgun	SSV Track 1	7	31 Jul	12:07	12:45
M/V *Storm Warning*	SSC Track 1	5	1 Aug	01:19	01:39

2.3.2. Long-Range Measurements

The dipping hydrophone was used by HDR Inc. outside the barrier islands after 25 August 2012 as part of fulfilling the IHA requirements to measure received levels from the survey at locations along the bowhead whale migration route outside the islands after the nominal start of the bowhead migration.

HDR Inc. conducted the measurements at locations M1-M8 (Figure 7) and detailed in Table 3. These locations were selected to align with the AMAR deployment locations. Eight measurements were conducted, and relevant non-acoustic data were duly logged. The settings of the supplied recording instrument, however, were altered by its operators during the acquisition program in an attempt to address a perceived lack of signal, leading to one measurement not producing valid data. After the conclusion of the survey, JASCO sourced the navigation data from CCGVeritas and NCS-Subsea and correlated the recording times with vessel movements.

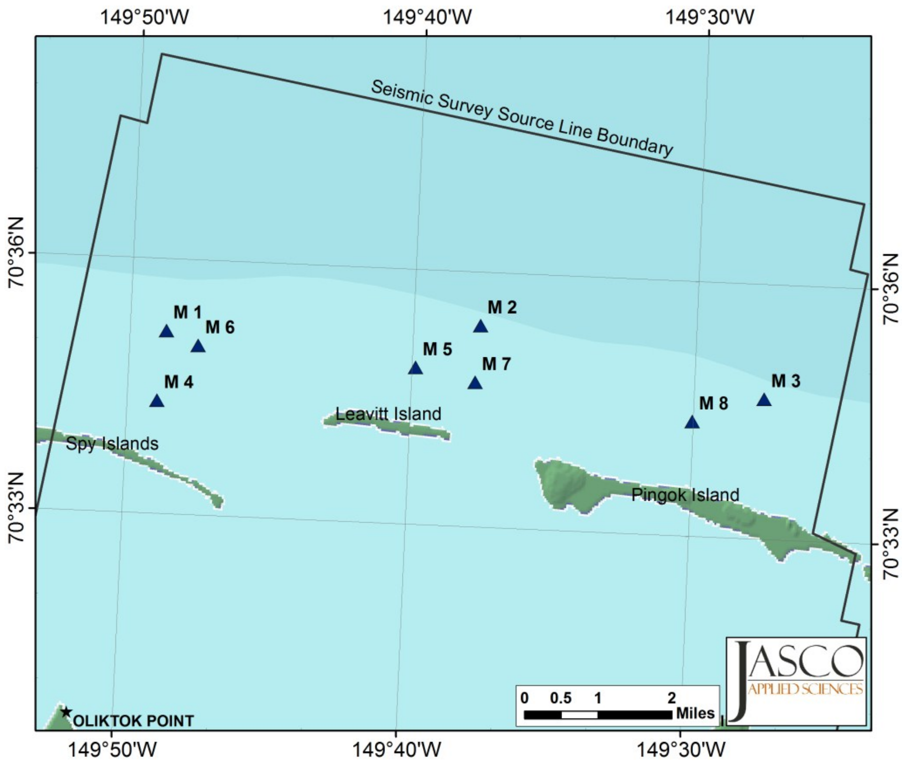


Figure 7. Dipping hydrophone sample locations; recommended (P1, P2, and P3) and measured (M1–M8).

Table 3. Dipping hydrophone locations (WGS-84), deployment, and retrieval times for the long-range measurements. Dates and times are in Alaska Daylight Time. Water depths were as measured at time of deployment.

Rec No.	Location	Date (AKDT)	Deployment (AKDT)	Retrieval (AKDT)	Latitude	Longitude	Water depth (m)
1	3	29 Aug	12:24	12:39	70°35.157′	149°48.710′	11.6
2	2	29 Aug	13:00	13:14	70°35.380′	149°37.630′	12.2
3	1	29 Aug	13:35	13:50	70°34.653′	149°27.513′	11.0
4	3	1 Sept	12:38	12:52	70°34.334′	149°48.929′	6.4
5	2	1 Sept	13:34	13:47	70°34.857′	149°39.856′	10.4
6	3	5 Sept	13:48	14:02	70°35.000′	149°47.560′	8.5
7	2	5 Sept	15:02	15:18	70°34.713′	149°37.738′	9.1
8	1	5 Sept	15:33	15:48	70°34.357′	149°30.023′	8.2

2.3.3. Long-Term Measurements

The AMARs for long-term measurements were deployed in strategic locations within the seismic survey area (Figure 8) with the primary goal of examining the degree to which the barrier islands block seismic survey sound propagation. This was achieved by comparing the peak and rms SPL levels received at three AMAR locations: two outside and one inside the barrier islands. These locations were selected so that AMAR 1 and AMAR 2 were aligned with a navigable channel between the islands, while AMAR 3 was positioned so that it could only receive sound that travelled out of the lagoon passing through an island.

Data from the AMARs were also used to examine the contribution of the seismic survey to the acoustic environment over the survey period. The AMARs were deployed one day prior to the seismic survey start (28 July), and retrieved 2-3 days after the survey had ended (6 Sep).

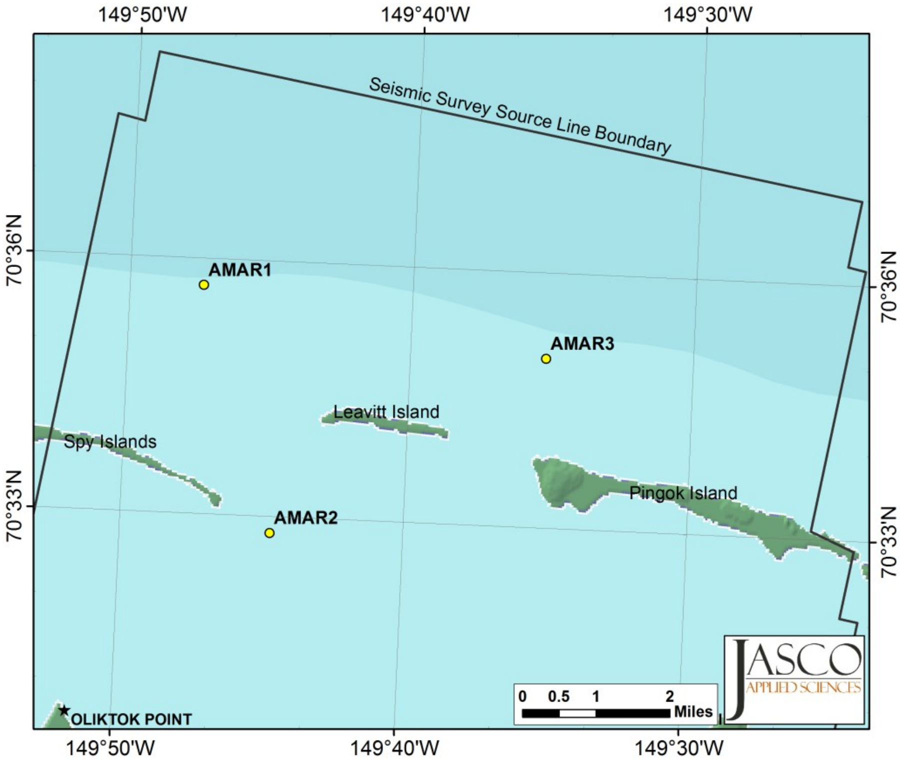


Figure 8. AMAR deployment locations in the seismic survey area.

Table 4. AMAR location (WGS-84) and deployment and retrieval times (AKDT) for the acoustic measurements. Water depths were measured at time of deployment.

AMAR	Deployment	Retrieval	Latitude	Longitude	Water depth (m)
1	27 Jul 13:39	9 Sep 08:50	70°35.695′ N	149°47.414′ W	12.2
2	27 Jul 12:57	7 Sep 12:01	70°32.821′ N	149°44.676′ W	2.8
3	27 Jul 15:05	9 Sep 09:33	70°34.992′ N	149°35.208′ W	12.5

2.4. Data Analysis

2.4.1. Noise Metrics

Underwater sound amplitude is measured in decibels (dB) relative to a fixed reference pressure of $p_o = 1$ μPa; however, the magnitude of impulsive noise, e.g., from seismic airguns, is not, in general, proportional to instantaneous acoustic pressure and so several sound level metrics are commonly used to evaluate the magnitude of impulsive noise and its effects on marine life.

The zero-to-peak SPL, or peak SPL (L_{pk}, dB re 1 μPa), is the maximum instantaneous sound pressure level in a stated frequency band attained by an impulse, $p(t)$:

$$L_{pk} = 10\log_{10}\left(\frac{\max\left(\left|p^2(t)\right|\right)}{p_o^2}\right) \quad (1)$$

The root-mean square (rms) SPL (L_p, dB re 1 μPa) is the rms pressure level in a stated frequency band over a time window (T, s) containing the pulse:

$$L_p = 10\log_{10}\left(\frac{1}{T}\frac{\int_T p^2(t)dt}{p_o^2}\right) \quad (2)$$

The rms SPL can be thought as a measure of the average pressure or as the "effective" pressure over the duration of an acoustic event, such as the emission of one acoustic pulse. Because the window length, T, is a divisor, pulses more spread out in time have a lower rms SPL for the same total acoustic energy.

By convention, when computing airgun safety radii, T is often defined as the "90% energy pulse duration", containing the central 90% (from 5% to 95% of the total) of the cumulative square pressure (or energy) of the pulse, rather than over a fixed time window (Malme et al. 1986, Greene 1997, McCauley et al. 1998). The 90% rms SPL (L_{p90}, dB re 1 μPa) in a stated frequency band is calculated over this 90% energy time window, T_{90}:

$$L_{p90} = 10\log_{10}\left(\frac{1}{T_{90}}\int_{T_{90}} p^2(t)dt \Big/ p_o^2\right) \quad (3)$$

The SEL (L_E, dB re 1 μPa^2·s) is the time integral of the squared pressure in a stated frequency band over a stated time interval or event. The per-pulse SEL is calculated over the time window containing the entire pulse (i.e., 100% of the acoustic energy), T_{100}:

$$L_E = 10\log_{10}\left(\int_{T_{100}} p^2(t)dt \Big/ T_o p_o^2\right) \quad (4)$$

where T_o is a reference time interval of 1 s. The per-pulse SEL, with units of dB re 1 μPa·√s, or equivalently dB re 1 μPa^2·s, represents the total acoustic energy delivered over the duration of the acoustic event at a receiver location. It is a measure of sound energy (or exposure) rather than sound pressure, although it is not measured in energy units. SEL can be a cumulative metric if it is calculated over periods containing multiple pulses.

2.4.2. Seismic Airgun SSVs: Per-Shot Pulse Levels

The magnitude of each recorded pulse from the airgun 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. Determine start time of the impulsive pressure signal with an automatic power-threshold detector.
3. Compute peak SPL (symbol L_{pk}) according to Equation 1.
4. Compute cumulative square pressure over the duration of the pulse.
5. Determine the 90% time window length (T90) and compute 90% rms SPL (symbol L_{p90}) according to Equation 3.
6. Compute SEL (symbol L_E) according to Equation 4 over the duration of the pulse.

Sound levels shown were recorded on the more sensitive TC4032 hydrophone unless clipping or non-linear effects near saturation were observed, in which case sound levels from the less sensitive TC4043 hydrophone were substituted. These higher levels generally occurred within 1000 m of the closest point of approach (CPA) of the source to the recorder.

2.4.3. Vessel SSCs: Continuous Sound Levels

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

2.4.4. SSVs and SSCs: Sound Level versus Range and SPL Threshold Radii

Acoustic data were analyzed using custom processing software to determine peak and rms SPLs and per-pulse sound exposure levels (SELs) versus range from the airgun sources. The data were processed as follows:

1. Airgun pulses in the OBH recordings were identified using an automated detection algorithm.
2. Waveform data were converted to units of µPa using the calibrated hydrophone sensitivity of each OBH.
3. For each pulse, the distance to the airgun array was computed from the GPS deployment coordinates of the OBHs and the time-referenced navigation logs of the survey vessel.
4. The airgun pulses were processed to determine peak sound pressure level (Peak SPL), 90% rms sound pressure level, (SPL) and sound exposure level (SEL) at the receiver location.

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

$$L_{p90} = \mathrm{SL} – \mathrm{n}\ \log\mathrm{R} – \alpha\mathrm{R}, \text{ or} \quad (7)$$

$$L_{p90} = \mathrm{SL} – \mathrm{n}\ \log\mathrm{R} \quad (8)$$

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

The best-fit line was shifted upward (in dB) to exceed 90% of the rms SPL data points, yielding the 90th percentile fit. The 90th percentile best-fit values for SL, n, and α are shown in the SPL plot annotations in the following sections. The distances to the SPL thresholds (120-190 dB re 1 µPa in 10 dB increments) are tabulated for each source, for both the best-fit and 90th percentile fit lines.

2.4.5. Spectral Analysis

The broadband frequency content of each source was presented in three formats:

- spectrogram
- spectral density over a specified time window
- 1/3–octave band levels

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

$$f_{ci} = 10^{i/10},\ i = 1, 2, 3, \ldots \qquad (9)$$

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

The spectral analysis is useful in the context of sound source verification as it enables a more complete interpretation of the results. This includes relative amplitude comparison and examination of how the pulse changes with travelled distance in both the frequency and time domains.

2.4.6. Automated Processing

A specialized computing platform operating at about 800 times greater than real-time recording (e.g., 800 h of recorded data could be analyzed in 1 h of computing time) was used to analyze ambient noise. The following section provides an overview of the processing stages; more information is in Appendix A.

2.4.6.1. Ambient Data Analysis and Time Series Analysis

The frequency domain ambient analysis provides 1 Hz resolution spectral density values for each minute of a recording. These values are directly comparable to the Wenz curves (Figure 9; Wenz 1962), which are representative of typical sound levels in the ocean. The ambient analysis also provides 1/3-octave and decade sound pressure levels for each minute of data.

SpectroPlotter's time series toolchain, which finds the peak amplitudes, peak-to-peak amplitudes, and rms amplitudes of the time series for each minute of data, performed time-domain ambient analysis.

This information is presented as percentiles, spectrograms and 1/3-octave band level plots.

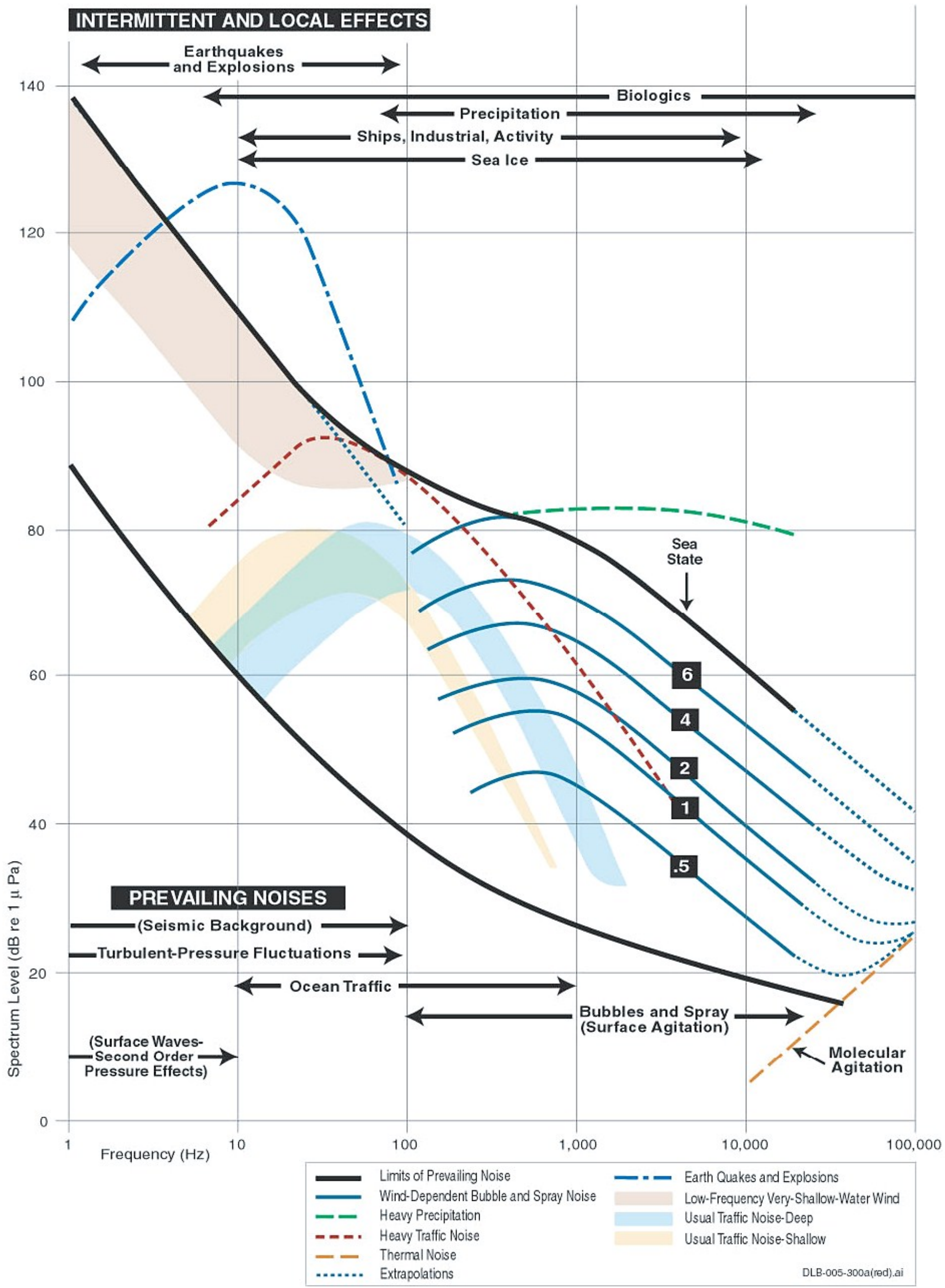


Figure 9. The Wenz curves describing pressure spectral density levels of marine ambient noise from weather, wind, geologic activity, and commercial shipping (Ocean Studies Board 2003 adapted from Wenz 1962). Thick lines indicate limits of prevailing noise.

3. Results

3.1. SSV/SSC Outside Barrier Islands

All airgun configuration trials outside the barrier islands were towed at 2 meters, the planned operational depth. Recorders were approximately placed at the 190, 180 and 160 dB isopleths in the across-track (broadside) direction as estimated in pre-season modeling. Because no direct broadside measurements were made near the 120 dB sound level, the analysis was based on data extrapolated from curves fitted to the measured data to determine the range at this level.

3.1.1. Sound Speed Profiles

The sound speed profile was measured in three locations outside the barrier islands (Figures 10 through 12), distributed across the area (Figure 13). The profile is reasonably similar at all locations, with a decreasing sound speed down to about 5-6m and a constant speed below 6m of 1436 m/s. The near-surface sound speed is substantially higher at the Cast 4 site, up to about 1455 m/s, compared to about 1439 m/s at the Cast 1 and 2 sites. All of these profiles induce a downward refracting propagation regime.

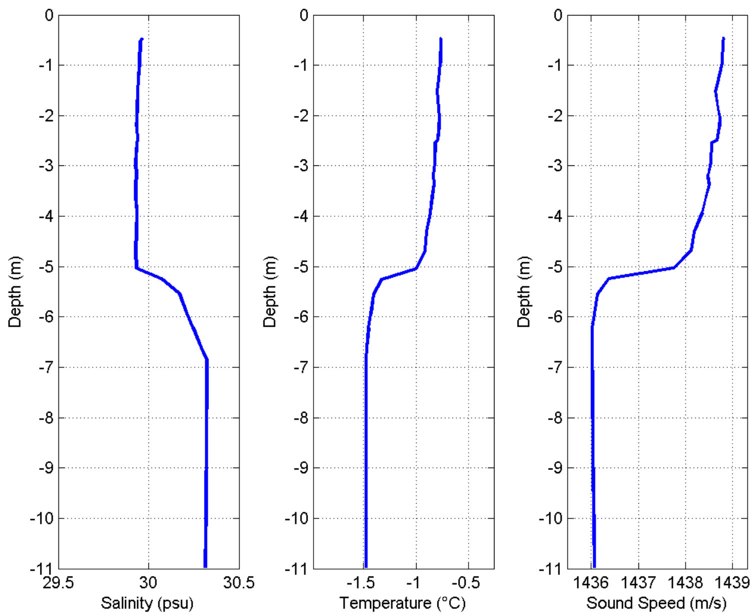


Figure 10. (left) Salinity, (center) temperature, and (right) sound speed profiles from CTD Cast 1 at 09:47:38 AKDT, 26 Jul 2012 at 70° 35.685' N, 149° 47.698' W, outside the barrier islands.

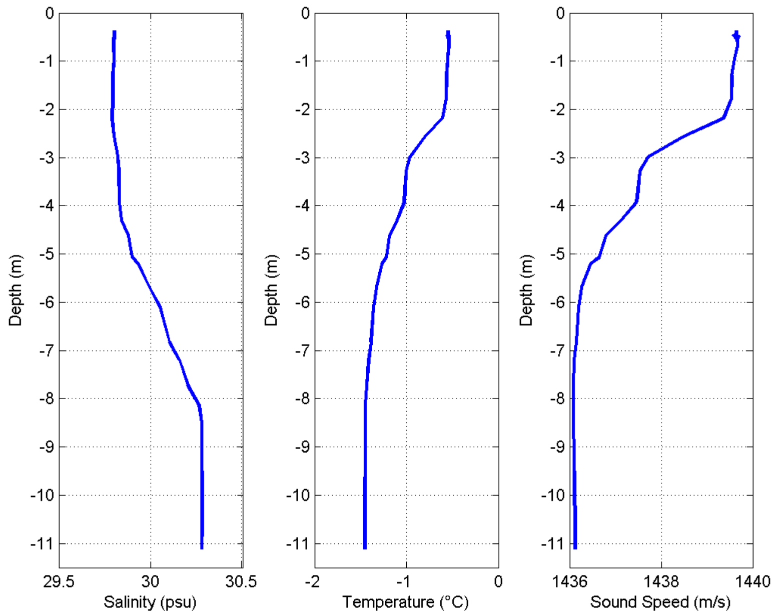


Figure 11. (left) Salinity, (center) temperature, and (right) sound speed profiles from CTD Cast 2 at 10:43:04 AKDT, 27 Jul 2012 at 70° 34.973' N, 149° 35.134' W, outside the barrier islands.

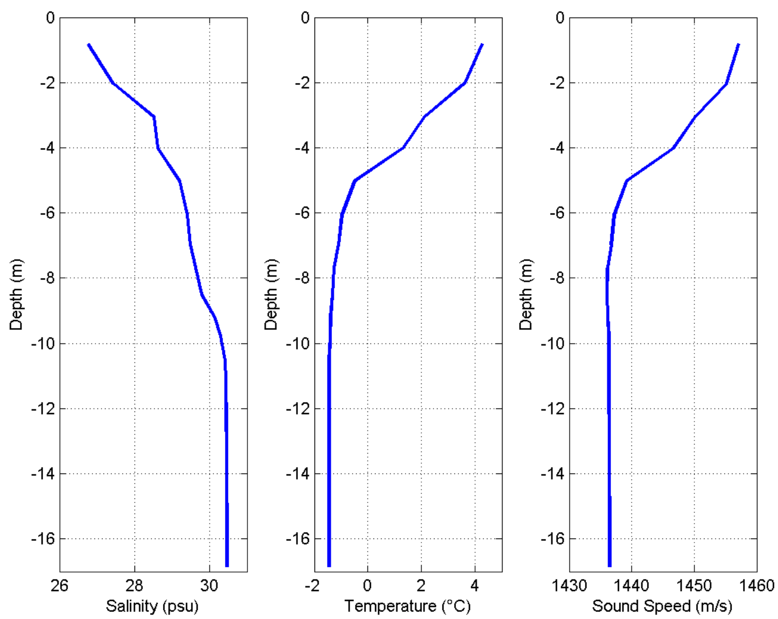


Figure 12. (left) Salinity, (center) temperature, and (right) sound speed profiles from CTD Cast 4 at 01:23:47 AKDT, 29 Jul 2012 at 70° 37.995' N, 149° 25.141' W, outside the barrier islands.

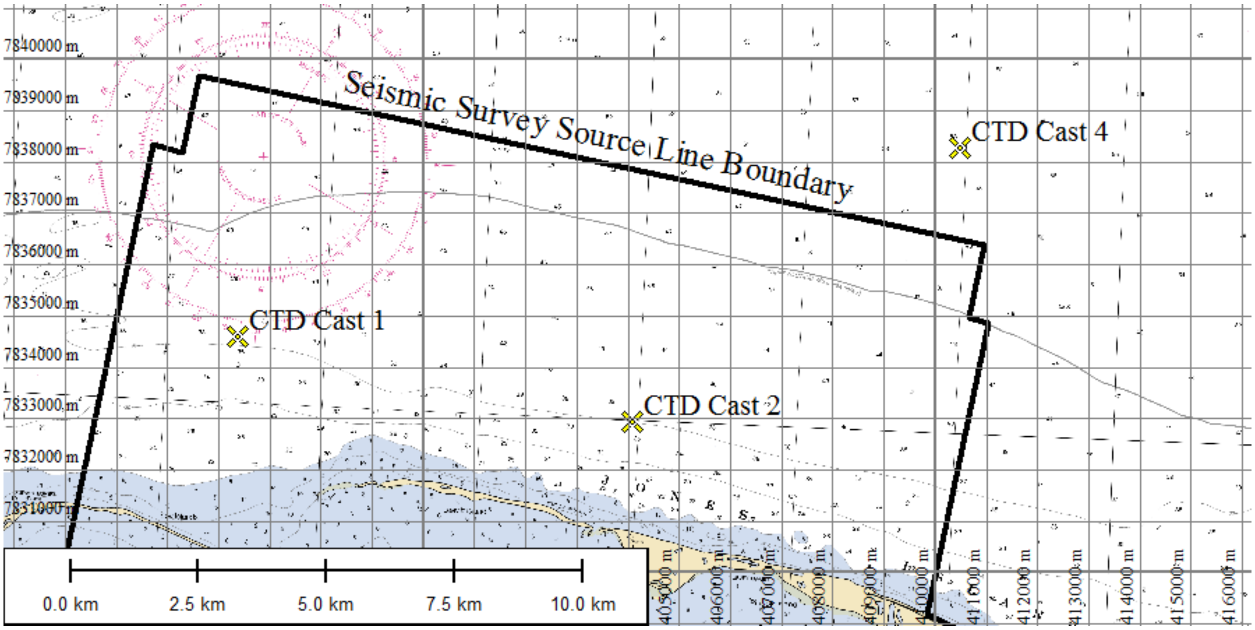


Figure 13. Sound speed profile measurement locations, outside the barrier islands.

3.1.2. 640 in^3 Airgun Array

Peak SPL, 90% rms SPL, and SEL for each pulse were computed from acoustic data recorded on OBHs A2 through C2. Figure 14 shows sound levels from the 640 in^3 airgun versus slant range measured in the endfire (along the direction of tow) and broadside (across track) directions for SSV Track 2. The closest broadside measurements, from OBH A2 were included in the endfire calculations. Tables 5 and 6 list ranges to various rms SPL thresholds for each of the fits in Figure 14. Figures 15 and 16 show the spectrograms for the endfire and broadside orientations, Figures 17 and 18 show the waveform and spectra.

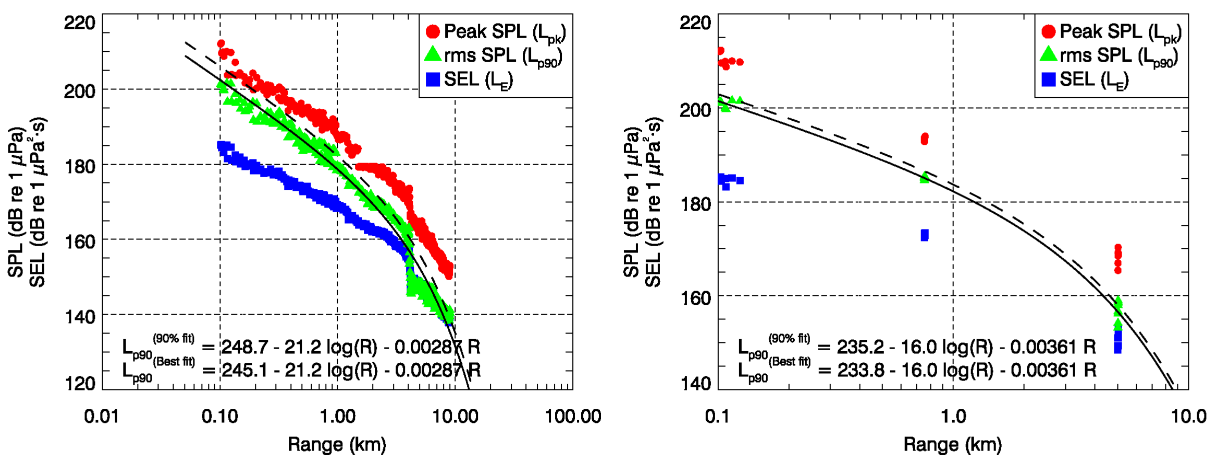


Figure 14. Peak SPL, rms SPL, and sound exposure level (SEL) versus slant range for the 640 in^3 airgun pulses: (left) Endfire and (right) broadside directions, outside the barrier islands. Solid line is the best-fit line to the 90% rms SPL. Dashed line is the best-fit adjusted to exceed 90% of the 90% rms SPL.

Table 5. *Endfire threshold radii:* Distance from the 640 in^3 airgun array, outside the barrier islands, to 90% rms SPL thresholds determined from the best-fit lines in Figure 14.

Endfire Distance in meters (outside barrier islands)		
Threshold (dB re 1 µPa)	*Best-Fit*	*90th Percentile*
190	355	502
180	891	1196
170	1916	2420
160	3483	4163
120	13 150	14 163

Table 6. *Broadside threshold radii*: Distance from the 640 in^3 airgun array, outside the barrier islands, to 90% rms SPL thresholds determined from the best-fit lines in Figure 14.

Broadside Distance in meters (outside barrier islands)		
Threshold (dB re 1 µPa)	*Best-Fit*	*90th Percentile*
190	436	516
180	1223	1386
170	2568	2803
160	4334	4616
120	13 270	13 624

Figures 15 and 16 show pulse spectrograms from measurements taken at ranges close to the 190 dB modeled threshold radius of 120 m (Figure 16, endfire range 101 m) and 180 dB modeled threshold radius of 950m (Figure 15, endfire range 997 m, and Figure 16, broadside range 754 m). The broadside range of 754 m is the closest point of approach (CPA) range for OBH B1, deployed at that lateral offset perpendicular to the array tow path, and the closest point to the 180 dB modeled threshold radius of 950 m.

These measurements indicate strong water and substrate propagation at these distances, observable through the frequency range of the detected pulses (1 Hz to 10 kHz). Low frequency (<100 Hz) sounds propagate in the sub-bottom as the wavelengths are too large to be supported in the water column. The water and sub-bottom path acoustic energy components arrive almost simultaneously at ranges less than 1 km. The pulses at these ranges had a shorter 90% rms SPL length than the model predicted, partly because the difference between the rms SPL and SEL levels was larger than expected.

The measurement location close to the 160 dB modeled threshold (Figure 15, endfire range 5010 m), showed the pulse beginning to separate into different propagation modes, with energy below the 60 Hz Airy phase (at which the water and ground borne waves merge constructively) having travelled through the sub-bottom. The actual pulse length (Figure 17) is greater than predicted by the model, which resulted in a smaller difference between the rms SPL and SEL levels, contributing to a smaller threshold radius than the model predicted.

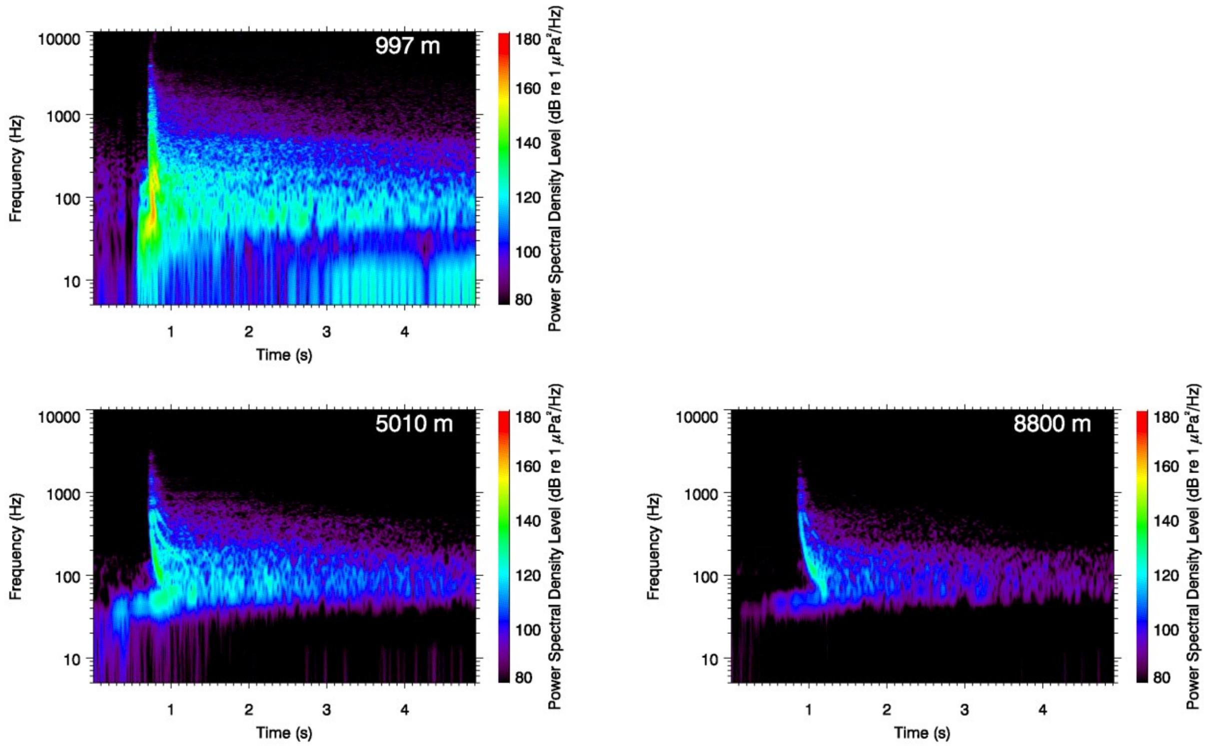


Figure 15. *Endfire*: Spectrograms of airgun pulses from the 640 in³ airgun array recorded on OBH A2 at three distances, 997 m, 5010 m and 8800 m; 8192-pt FFT, 96 kHz sample rate, Hanning window, 87.5% overlap.

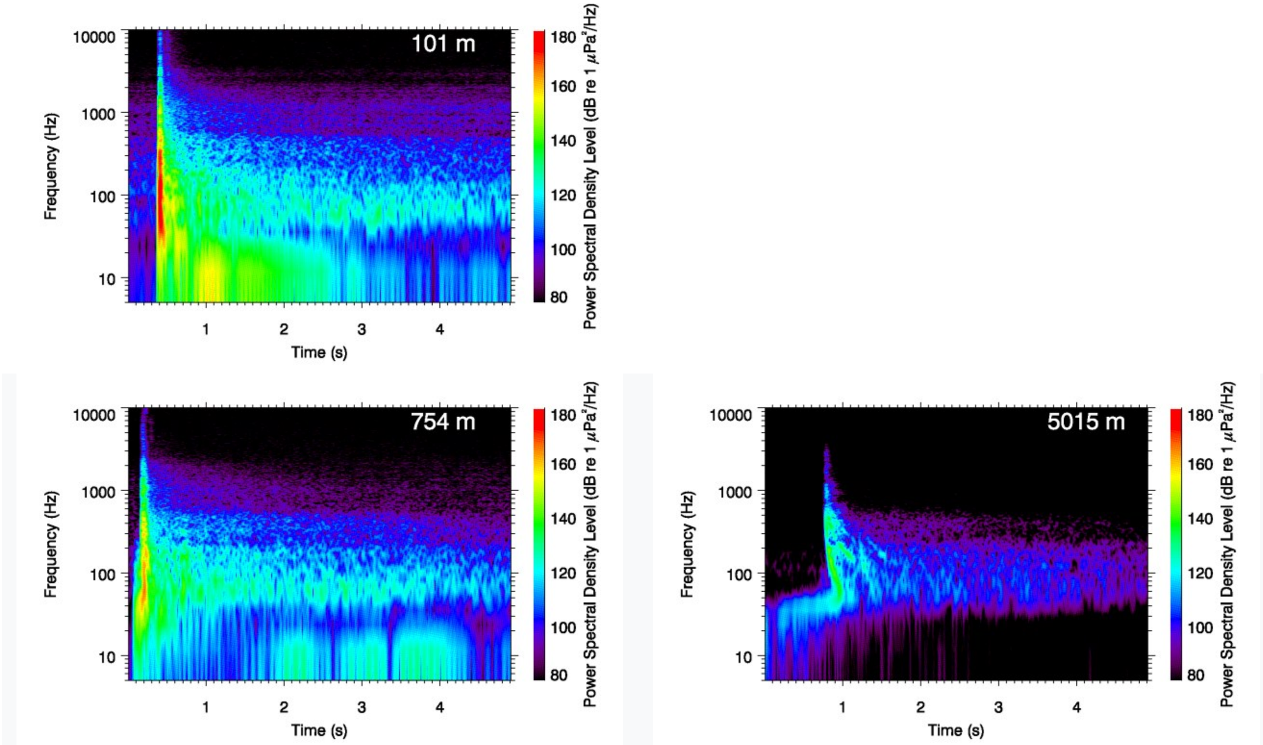


Figure 16. *Broadside*: Spectrograms of airgun pulses from the 640 in³ airgun array at the CPA for each OBH, 101 m to A2, 754 m to B2, 5015 m to C2; 8192-pt FFT, 96 kHz sample rate, Hanning window, 87.5% overlap.

The SEL spectral density of the pulses at the distances noted in Figures 17 and 18, show a diminishing trend, in the low frequency components and the components above 200 Hz, with distance from the source. Low frequency components are those below 50 Hz, but the diminishing trend was strongest below 10 Hz. This results in the 80-200 Hz components dominating the received signal at distances farther than about a kilometer from the source.

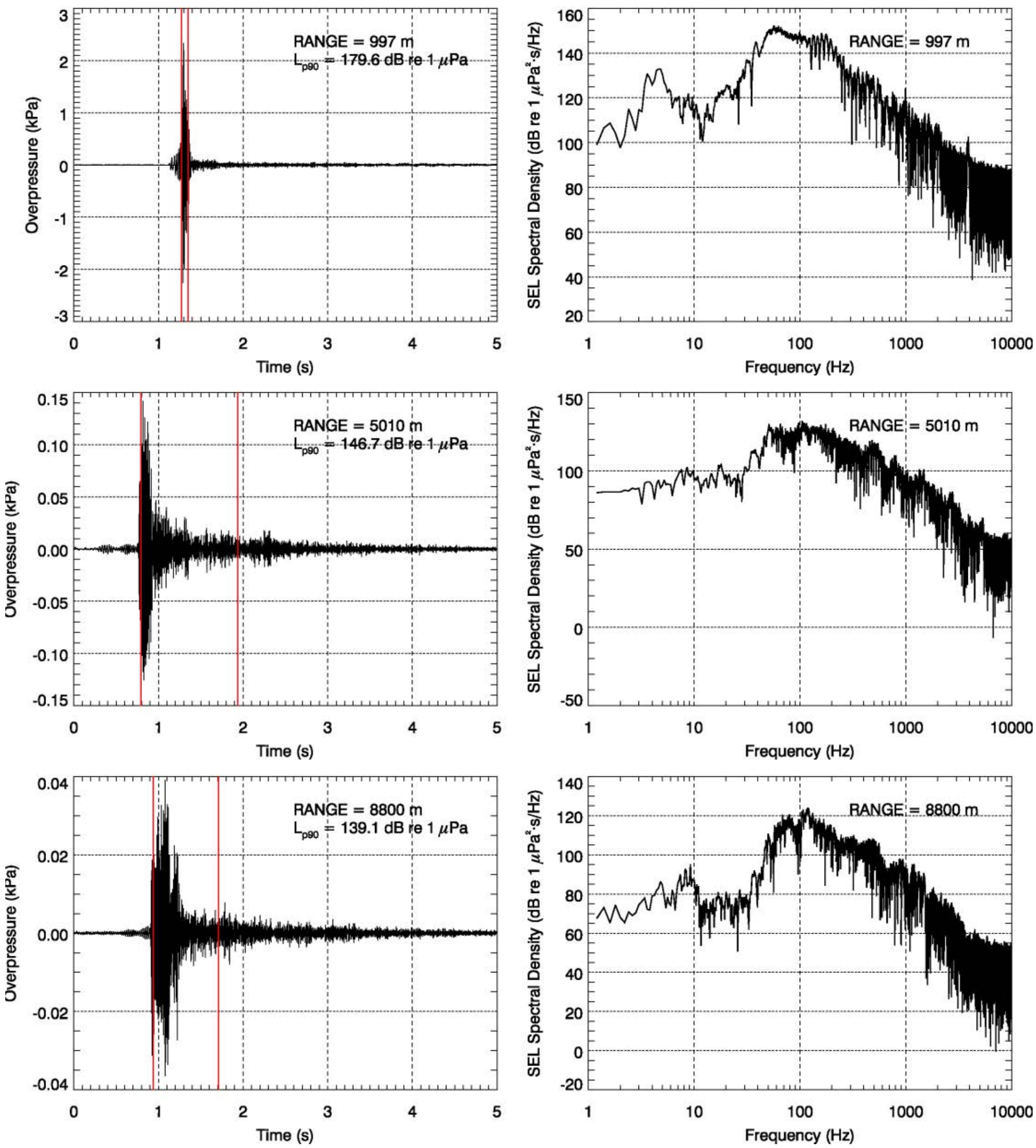


Figure 17. *Endfire*: (left) Waveform and spectra (right) corresponding SEL spectral density of 640 in³ airgun array pulses at three distances from OBH A2, 997 m, 5010 m, and 8800 m. The red bars on the waveform indicate the 90% energy pulse duration.

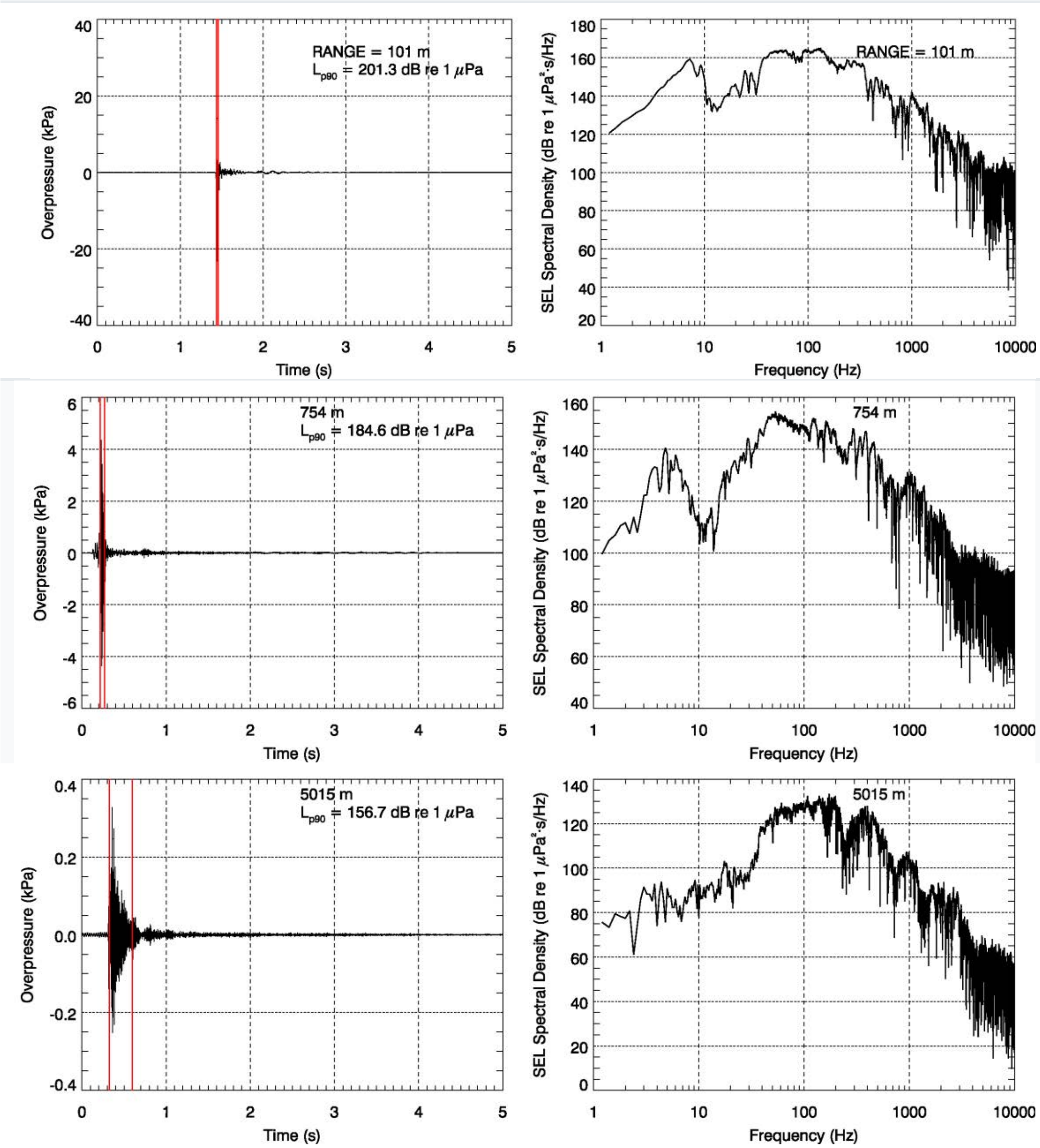


Figure 18. *Broadside*: (left) Waveform and spectra (right) corresponding SEL spectral density (right) plots of 640 in³ airgun array pulses array at the CPA for each OBH, 101 m to A2, 754 m to B2, 5015 m to C2. The red bars on the waveform indicate the 90% energy pulse duration.

3.1.3. 320 in³ Airgun Array

Peak SPL, 90% rms SPL and SEL for each shot were computed from acoustic data recorded on OBHs A2 through C2. Figure 19 shows sound levels from the 320 in³ airgun versus slant range measured in the endfire and broadside directions for SSV Track 2. The closest broadside measurements, from OBH A2 were included in the endfire calculations. Tables 7 and 8 list ranges to various rms SPL thresholds for each of the fits in Figure 19. Figures 20 and 21 show the spectrograms for the endfire and broadside orientations, Figures 22 and 23 show the waveform and spectra.

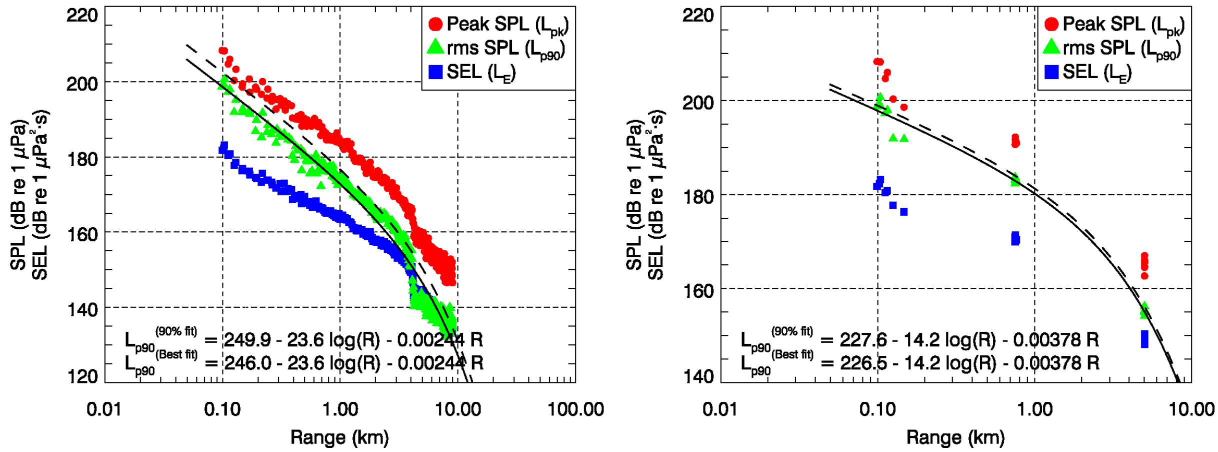


Figure 19. Peak SPL, rms SPL, and sound exposure level (SEL) versus slant range for the 320 in^3 airgun pulses in the (left) endfire and (right) broadside directions, outside the barrier islands. Solid line is the best-fit line to the 90% rms SPL. Dashed line is the best-fit adjusted to exceed 90% of the 90% rms SPL.

Table 7. *Endfire threshold radii*: Distance from the 320 in^3 airgun array, outside the barrier islands, to 90% rms SPL thresholds determined from best-fit lines in Figure 19.

Endfire Distance in meters (outside barrier islands)		
Threshold (dB re 1 µPa)	*Best-Fit*	*90th Percentile*
190	224	318
180	550	760
170	1238	1636
160	2456	3078
120	12 132	13 313

Table 8. *Broadside threshold radii*: Distance from the 320 in^3 airgun array, outside the barrier islands, to 90% rms SPL thresholds determined from the best-fit lines in Figure 19.

Broadside Distance in meters (outside barrier islands)		
Threshold (dB re 1 µPa)	*Best-Fit*	*90th Percentile*
190	311	360
180	1019	1134
170	2322	2484
160	4058	4265
120	12 771	13 027

Figures 20 and 21 show pulse spectrograms from measurements taken at close ranges: Figure 21, broadside range 99 m; Figure 20, endfire range 995 m; and Figure 21, broadside range 751 m. The broadside range of 751 m is the closest point of approach (CPA) for OBH B1, which was deployed at that lateral offset perpendicular to the array tow path. These measurements indicate strong water and substrate borne propagation at these distances, observable through the frequency range of the detected pulses (1 Hz to 10 kHz). There is also minimal delay in the arrival time of sub-bottom propagated energy, barely noticeable in the 995 m and 751 m plots in front of the main pulse and below 70 Hz.

The measurement at endfire range 5084 m (Figure 20) showed the pulse beginning to separate into different propagation modes, with energy below the 60 Hz Airy phase (at which the water and ground borne waves merge constructively) having travelled through the sub-bottom..

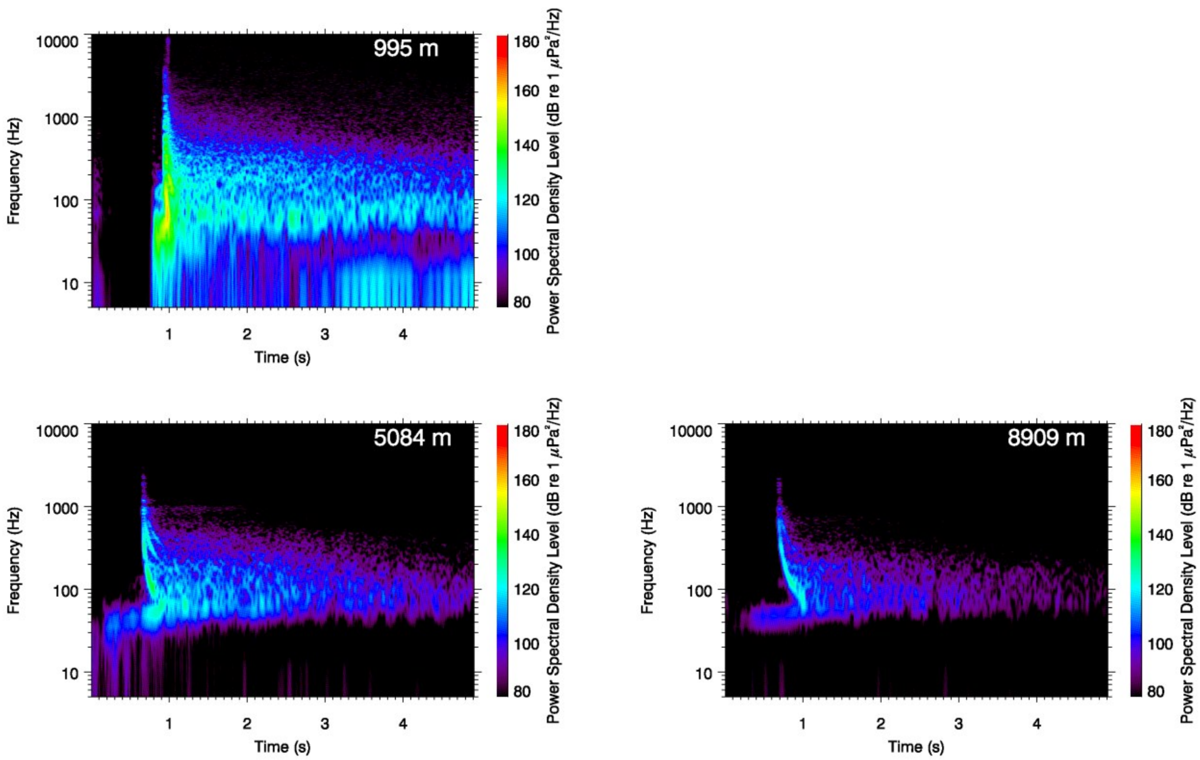


Figure 20. *Endfire*: Spectrograms of airgun pulses from the 320 in^3 airgun array at three distances from OBH A2, 998 m, 5084 m, and 8909 m; 8192-pt FFT, 96 kHz sample rate, Hanning window, 87.5% overlap.

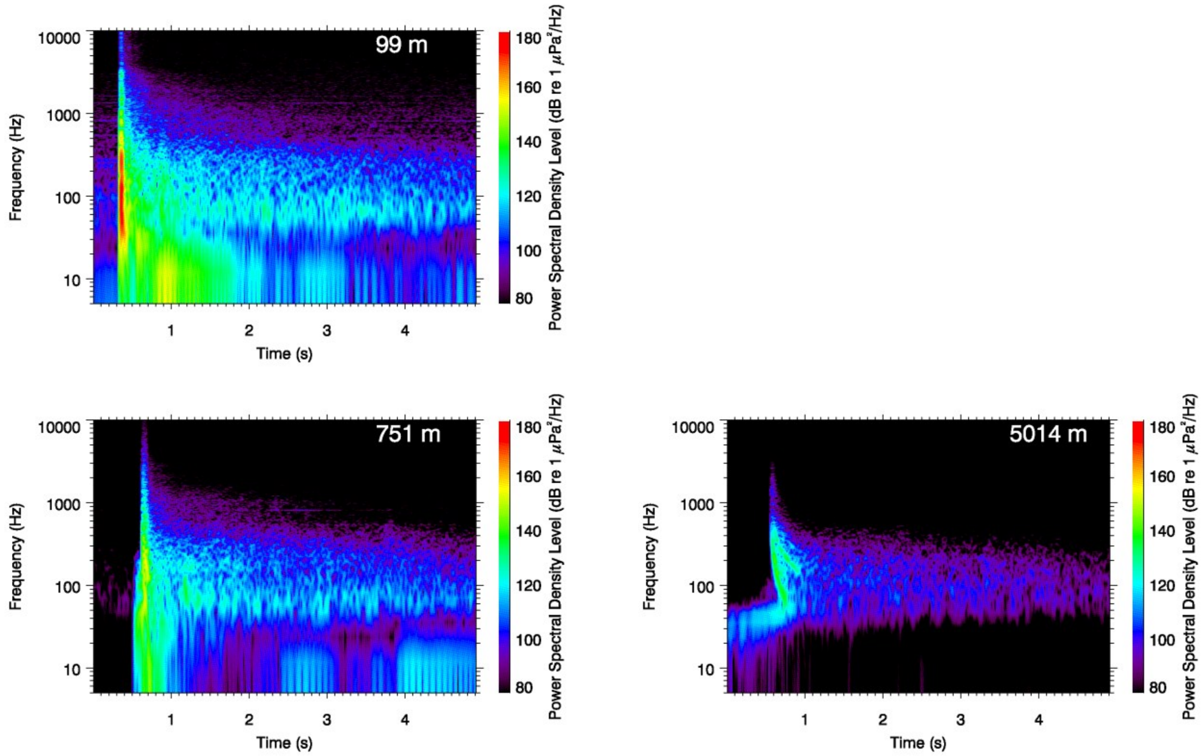


Figure 21. *Broadside*: Spectrograms of airgun pulses from the 320 in³ airgun array at the CPA to each OBH, 99 m to A2, 751 m to B2, 5014 m to C2; 8192-pt FFT, 96 kHz sample rate, Hanning window, 87.5% overlap.

The SEL spectral density of the pulses at the distances noted in Figures 22 and 23 show a diminishing trend in the low frequency components with distance from the source. Low frequency components are those below 50 Hz, but the diminishing trend was strongest below 10 Hz. This results in the 80–200 Hz components dominating the received signal at distances farther than about a kilometer from the source.

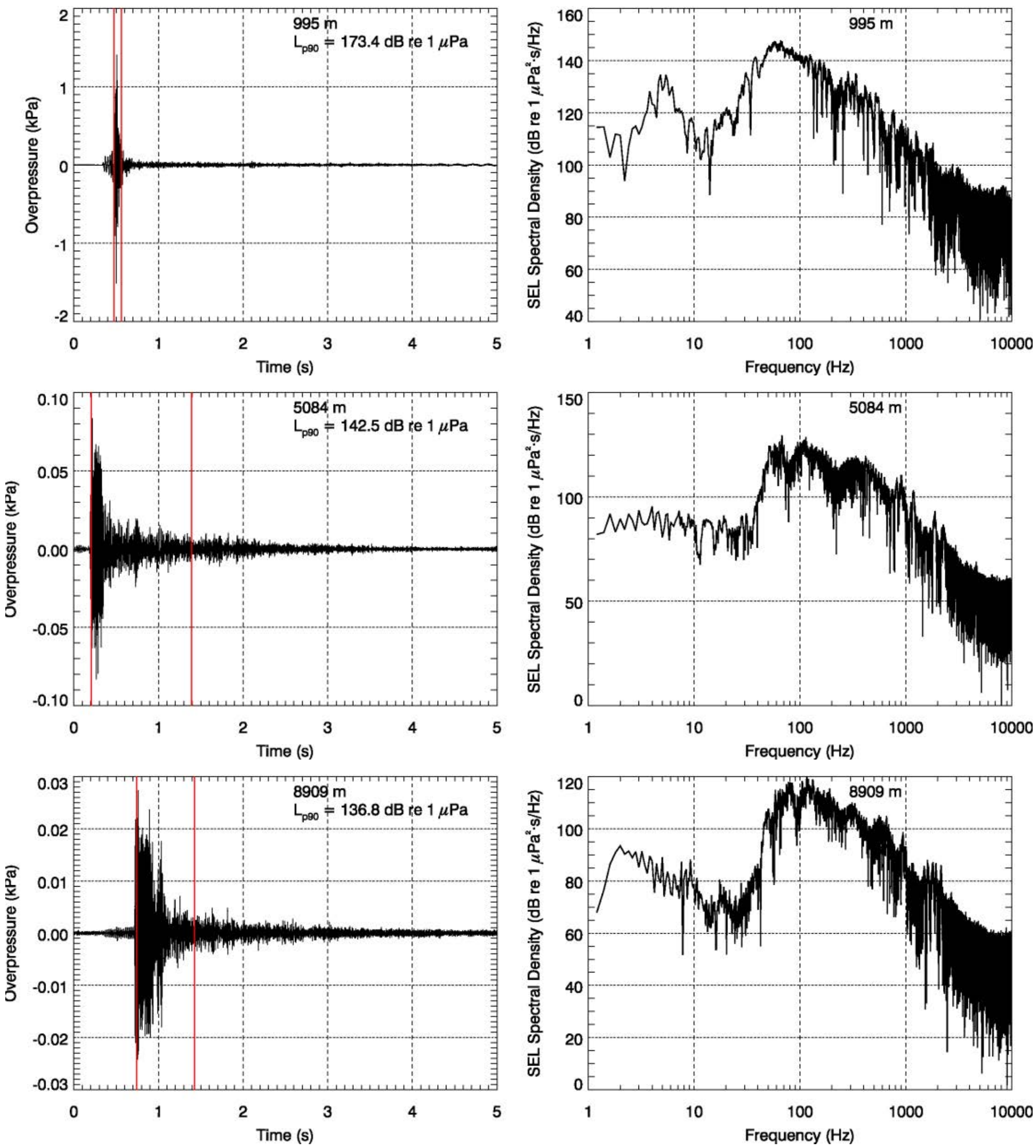


Figure 22. *Endfire*: (left) Waveform and spectra (right) corresponding SEL spectral density of 320 in³ airgun array pulses at three distances to OBH A2, 998 m, 5084 m, and 8909 m. The red bars on the waveform indicate the 90% energy pulse duration.

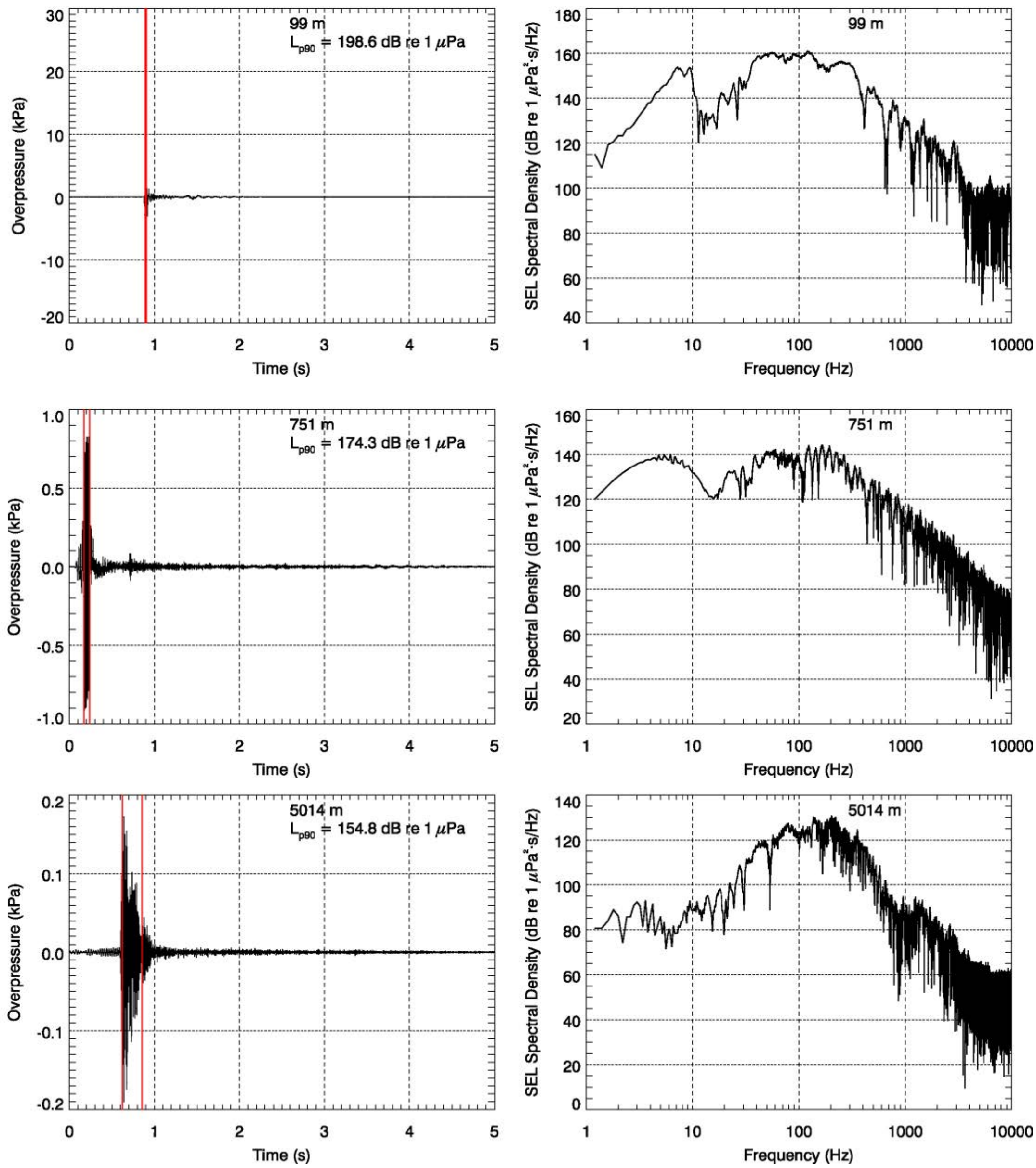


Figure 23. *Broadside*: (left) Waveform and spectra (right) corresponding SEL spectral density of 320 in³ airgun array pulses at the CPA to each OBH, 99 m to A2, 751 m to B2, 5014 m to C2. The red bars on the waveform indicate the 90% energy pulse duration.

3.1.4. 40 in^3 Mitigation Airgun

Peak SPL, 90% rms SPL, and SEL for each shot were computed from acoustic data recorded on OBHs A2 through C2. Figure 24 shows sound levels from the 40 in³ mitigation airgun versus slant range measured for SSV Track 2 in the endfire direction. Table 9 lists ranges to various rms SPL thresholds for each of the fits in Figure 24. The closest broadside measurements, from OBH A2 were included in the endfire calculations. The endfire and broadside results presented do not have any connection with source directionality (a single airgun is omnidirectional) and the different levels at matching distances are only an effect of the propagation environment as will be discussed in Section 4.1.

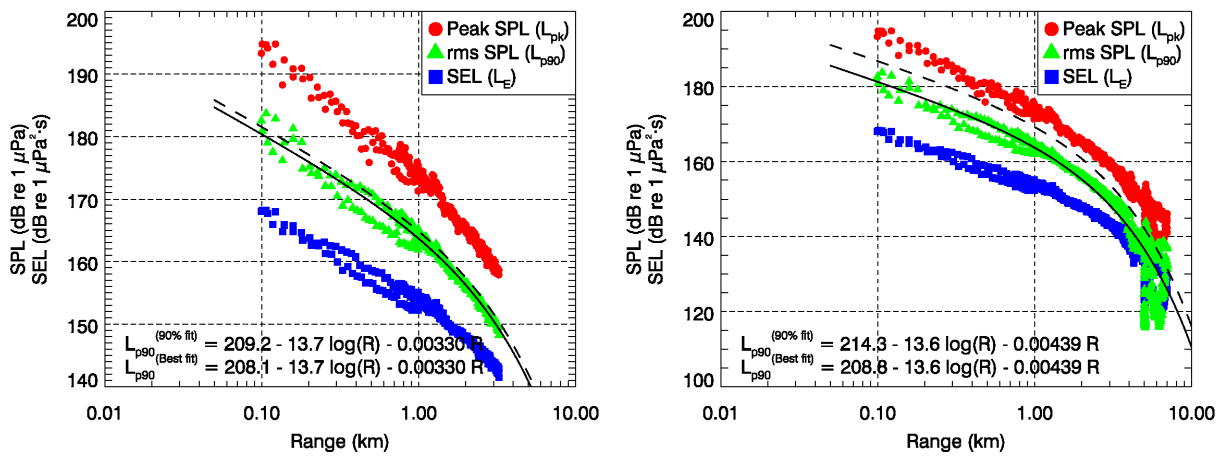


Figure 24. Peak SPL, rms SPL, and sound exposure level (SEL) versus slant range for the 40 in^3 mitigation airgun pulses in the endfire direction, outside the barrier islands. (left) Fit for 190–160 dB re 1 µPa, based only on measurements within a 3.5km range, (right) Fit for 150–120 dB re 1 µPa, based on all measurements. Solid line is the best-fit line to the 90% rms SPL. Dashed line is the best-fit adjusted to exceed 90% of the 90% rms SPL.

Table 9. Threshold radii for the 40 in^3 mitigation airgun, outside barrier islands as determined from best-fit lines to the 90% rms SPL versus distance data in Figure 24 (combination of left and right plots).

Distance in meters (outside barrier islands)		
Threshold (dB re 1 µPa)	*90% rms SPL Best-Fit 40 in^3*	*90% rms SPL 90th Percentile 40 in^3*
190	20	24
180	105	158*
170	465	539
160	1448	1602
120	8 133	9 221

*Actual maximum range from measurements.

Figures 25 and 26 show pulse spectrograms from measurements taken at ranges close to the 190 and 180 dB modeled threshold radius of <50 m (Figure 26, broadside range 99 m) and 160 dB modeled threshold radius of 810 m (Figure 25, endfire range 981 m; Figure 26, broadside range 751 m). The broadside range of 751 m is the closest point of approach (CPA) for OBH B1, deployed at that lateral offset perpendicular to the array tow path, and the closest point to the 160 dB modeled threshold radius of 810 m.

These measurements indicate strong water and substrate propagation at these distances, observable through the frequency range of the detected pulses (1 Hz to 10 kHz). The water and sub-bottom path energy arrive almost simultaneously at ranges less than 1 km. The pulses at these ranges had a shorter 90% rms SPL length than the model predicted, partly because the difference between the rms SPL and SEL levels was larger than expected.

A comparison between the endfire and broadband recorded pulse structures at equivalent ranges (Figure 25, endfire range 5016 m, and Figure 26, broadside range 5000 m) demonstrated that the received pulses have similar structure, but are different in received levels. The 40 in^3 mitigation airgun is omnidirectional at the source, therefore the different received levels are caused by propagation effects, a main contributor would be the sound speed profile combined with the increasing depth in the broadside direction.

The measurements beyond 5 km range (Figure 25, endfire ranges 5016 and 8918 m) showed the pulse separated into different propagation modes. The actual pulse length (Figure 27) is greater than predicted by the model, which resulted in a smaller difference between the rms SPL and SEL levels, contributing to a smaller threshold radius than the model predicted.

The SEL spectral density of the pulses at the aforementioned distances (Figures 27 and 28) showed a diminishing trend with distance from the source in the low frequency components (below 200 Hz) and the components above 1 kHz. This resulted in the 200–1 000 Hz components dominating the received signal at distances from the source beyond about a kilometer, which is different to outside the islands which has a much wider spectral pulse width.

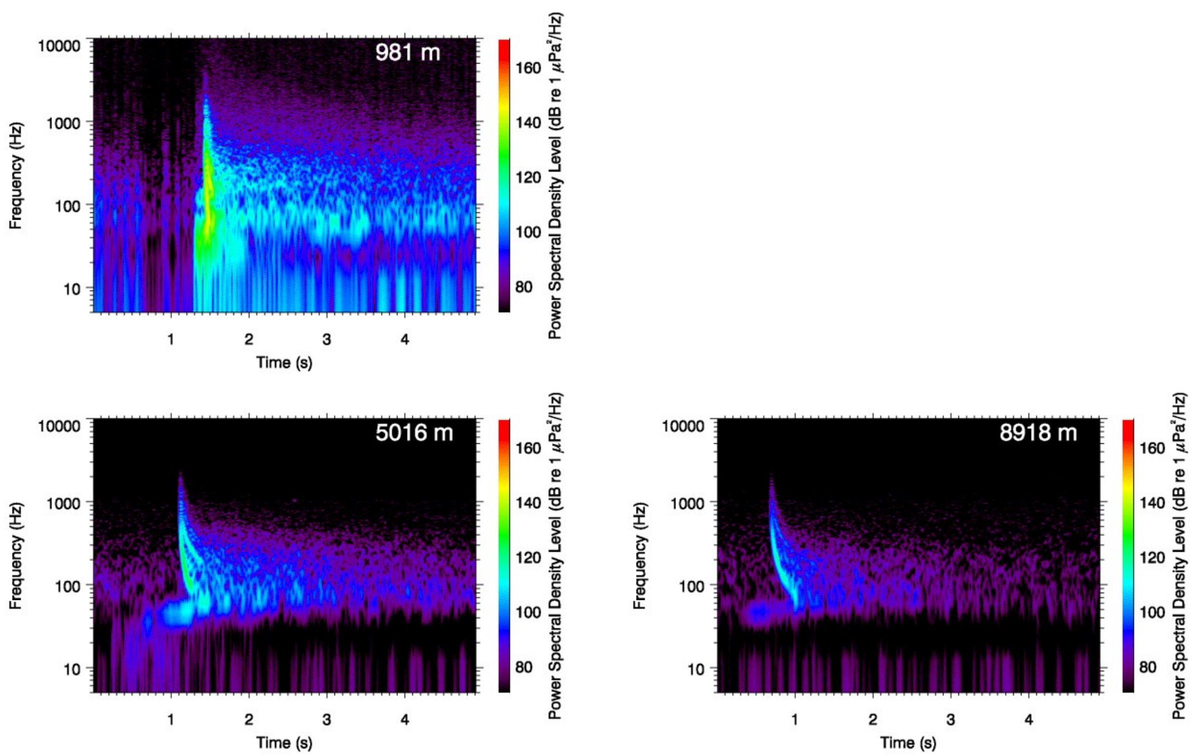


Figure 25. *Endfire*: Spectrograms of airgun pulses from the 40 in^3 mitigation airgun at three distances, 981 m, 5016 m, and 8918 m, 8192-pt FFT, 96 kHz sample rate, Hanning window, 87.5% overlap. Endfire only specified to differentiate measurement orientation.

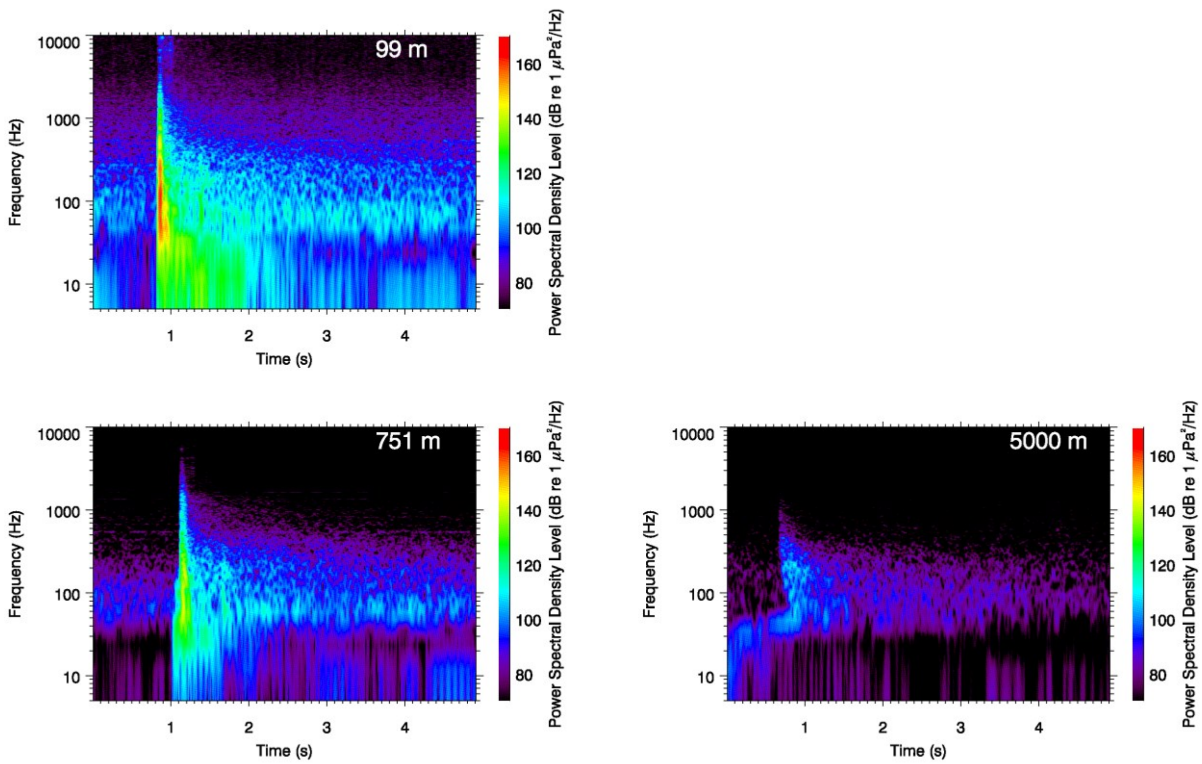


Figure 26. *Broadside*: Spectrograms of airgun pulses from the 40 in^3 mitigation airgun at the CPA to each OBH, 99 m to A2, 751 m to B2, 5000 m to C2; 8192-pt FFT, 96 kHz sample rate, Hanning window, 87.5% overlap. Broadside only specified to differentiate measurement orientation.

The SEL spectral density of the pulses at the distances noted in Figures 27 and 28, show a diminishing trend with distance from the source in the low frequency components (below 100 Hz) and the components above 200 Hz. This results in the 80–200 Hz components dominating the received signal at distances farther than about a kilometer from the source.

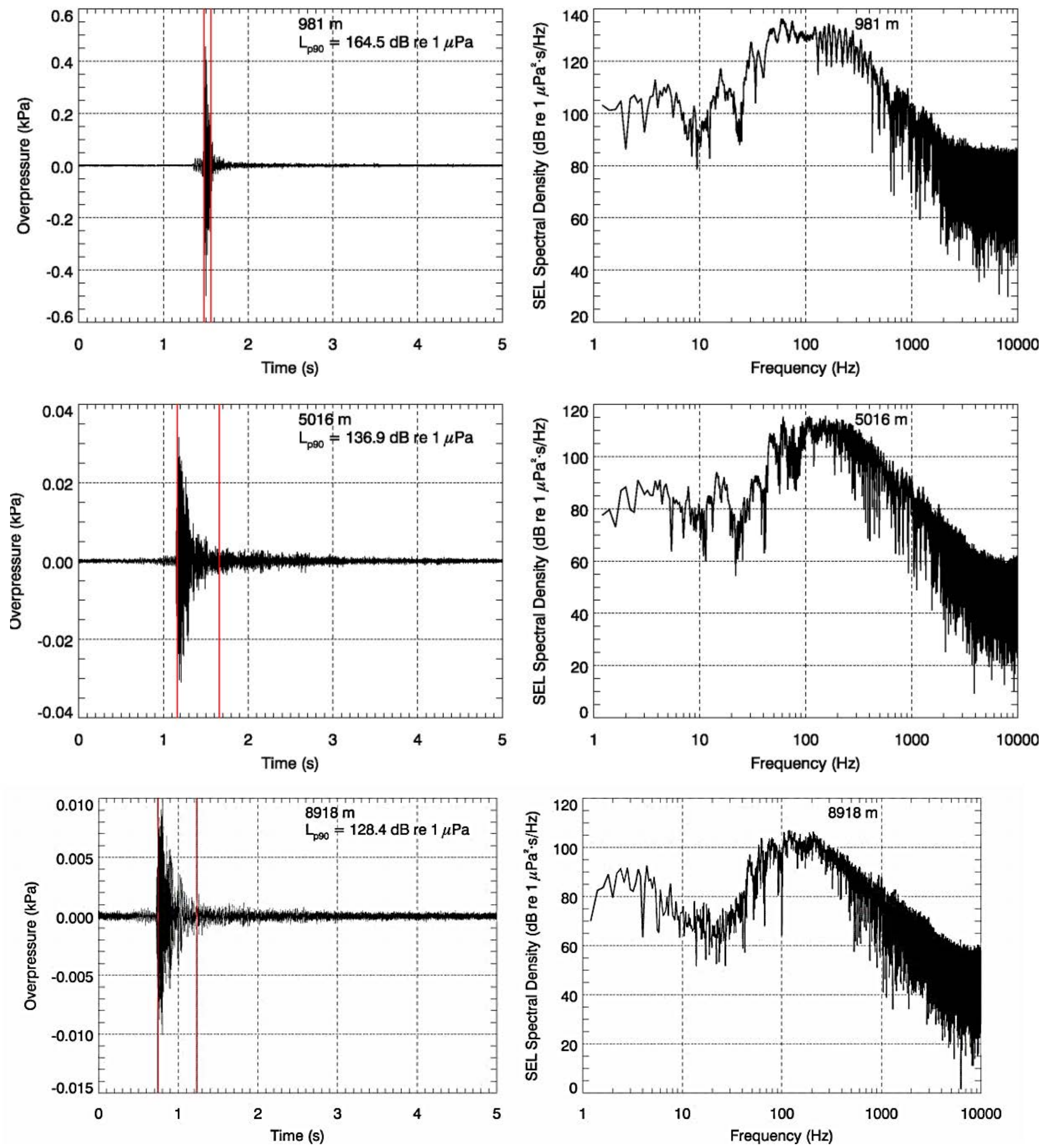


Figure 27. *Endfire*: (left) Waveform and spectra (right) corresponding SEL spectral density of 40 in^3 mitigation airgun pulses at three distances from OBH A2, 981 m, 5016 m, and 8918 m. The red bars on the waveform indicate the 90% energy pulse duration. Endfire only specified to differentiate measurement orientation.

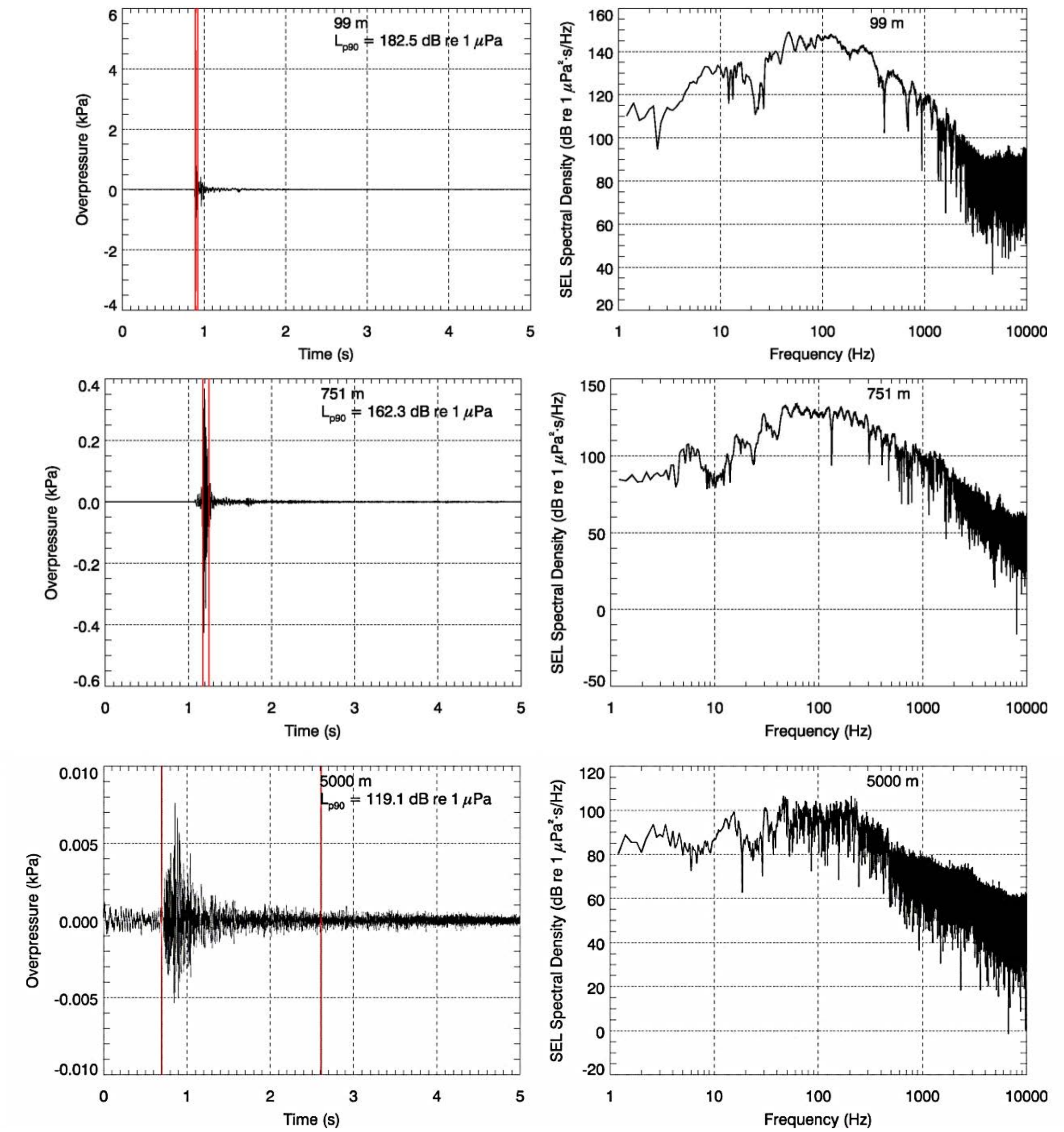


Figure 28. *Broadside*: (left) Waveform and spectra (right) corresponding SEL spectral density of 40 in^3 mitigation airgun pulses at the CPA to each OBH, 99 m to A2, 751 m to B2, 5000 m to C2. The red bars on the waveform indicate the 90% energy pulse duration. Broadside only specified to differentiate measurement orientation.

3.1.5. Resolution

SPLs were computed for the *Resolution*'s vessel noise during its transit along SSC Track 2 from the closest point of approach (CPA) to the end of the track. This section of SSC Track 2 was selected as most representative of the vessel noise characteristics in terms of signal quality and consistency. The water depth along the track (from cartographic records) ranges between 12.8 m and 13.4 m. The continuous noise levels were computed after low-pass filtering at 10 kHz in consecutive 1-second time windows, a standard processing step that eliminates potential contribution from high frequency non-vessel sounds.

Figure 29 shows the rms SPL levels versus time for the jetboat *Resolution* transiting at 5.5 kts, while Figure 30 presents the sound pressure levels versus range, with the best-fit and 90th percentile trend lines. To achieve the most accurate fits, data were analyzed in two sections: near-range (14 to 300 m), and far-range (300 to 3020 m). Data presented in the Figure 30 plots were recorded from the higher sensitivity TC4032 hydrophone. The ranges to the sound level thresholds of 160 to 120 dB re 1 µPa (rms) for the *Resolution* traveling at 5.5 kts are listed in Table 10. The vessel appears as a distributed sound source rather than a point at shorter ranges; therefore, reported radii that are within the near-field of the source should only be considered notional. The near-field threshold distance is proportional to the square of the source size divided by the wavelength of the sound; as a rough estimate, for a 20 m vessel and a fundamental tonal frequency of 75Hz the near-field threshold is at about 20 m. Levels measured at less than that range are still meaningful but may not represent the total acoustic output of the vessel. Figure 31 shows the spectrograms for the closest two OBHs; Figure 32 shows the corresponding power spectra at CPA.

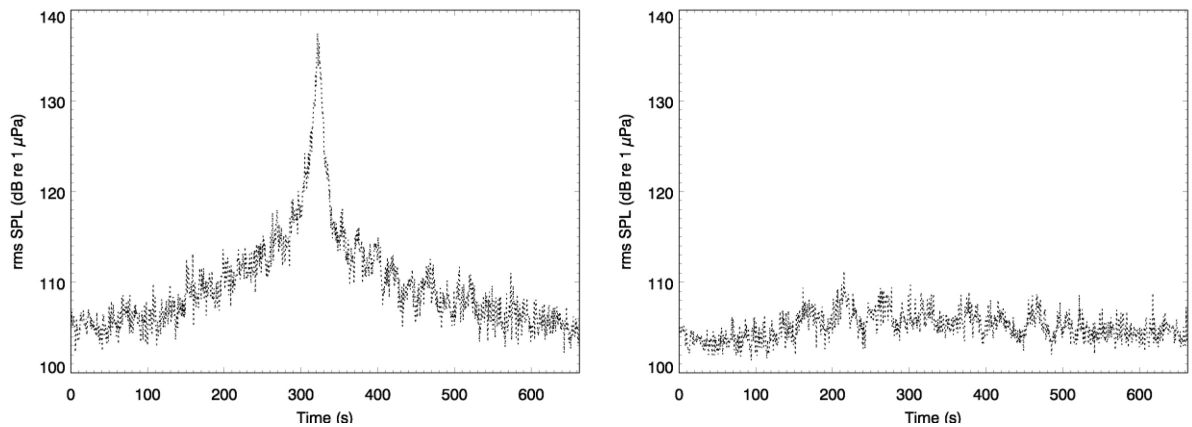


Figure 29. *Resolution* rms SPL versus time, in 1 s intervals while transiting at 5.5 kts (left) measured by OBH A2 with a 14.3 m CPA, and (right) B2 with a 664 m CPA.

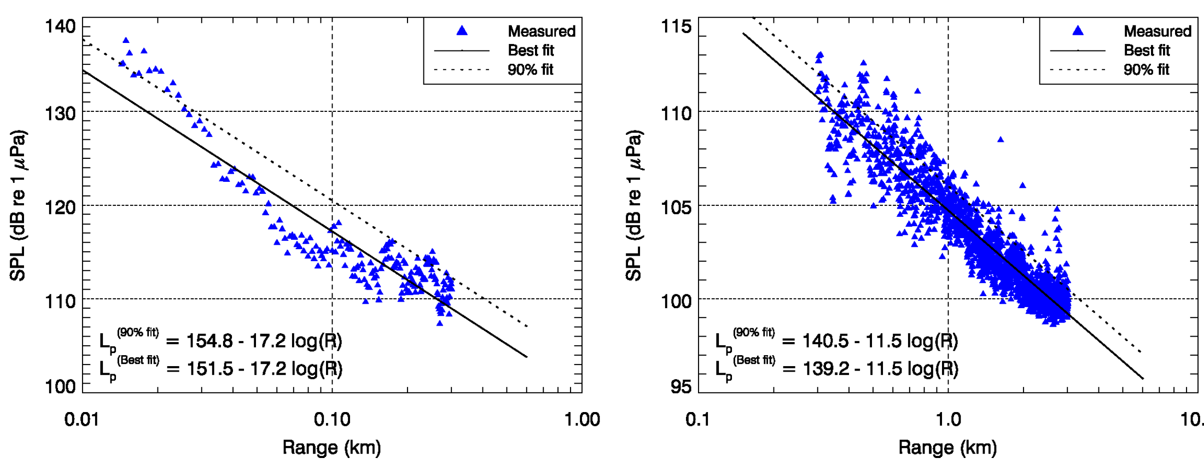


Figure 30. Sound pressure level (rms) versus slant range produced by the *Resolution* while it transited OBH A2 at 5.5 kts outside the barrier islands. (left) Fit for 160–130 dB re 1 µPa, based only on measurements between 14 and 300 m range, (right) fit for 120 dB re 1 µPa, based on measurements 300 to 3020 m. Solid line is the best-fit line to SPL data. Dashed line is the best-fit adjusted to exceed 90% of the SPL data.

Table 10. Threshold radii for the *Resolution* transiting at 5.5 kts at the SSC site, as determined from function fit to SPL versus distance data in Figure 30.

Threshold (dB re 1 µPa)	Best-Fit Line Radius (m)	90th Percentile Radius (m)
160	<1*	1*
150	1*	2*
140	5*	7*
130	17	28
120	47	61

*Extrapolated from minimum measurement range of 14.3 m. These distances are well inside the near-field of such a distributed source, and should be considered only as notional values.

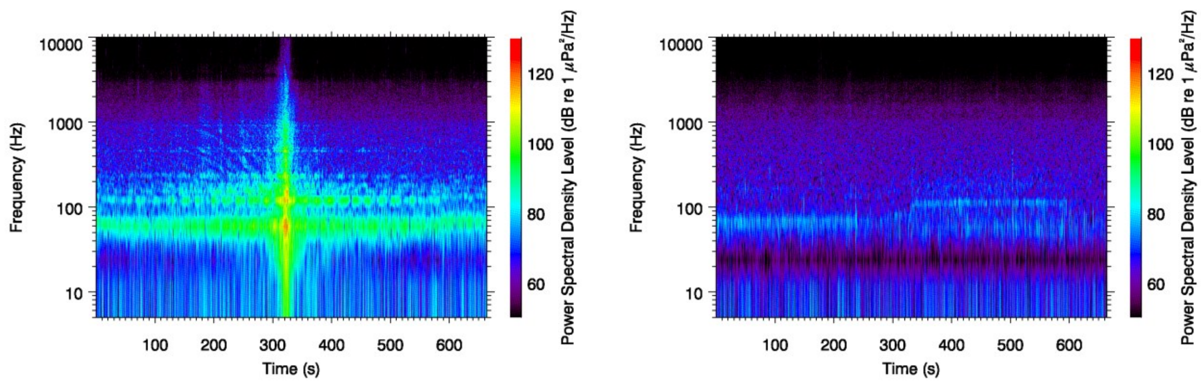


Figure 31. Spectrograms of the *Resolution* transiting at 5.5 kts, (left) from 1000 m either side of A2, with a CPA of 14.3 m, and (right) for the same interval from B2, with a CPA of 664 m. 8192 pt FFT, 96 kHz sample rate, Hanning window, 87.5% overlap.

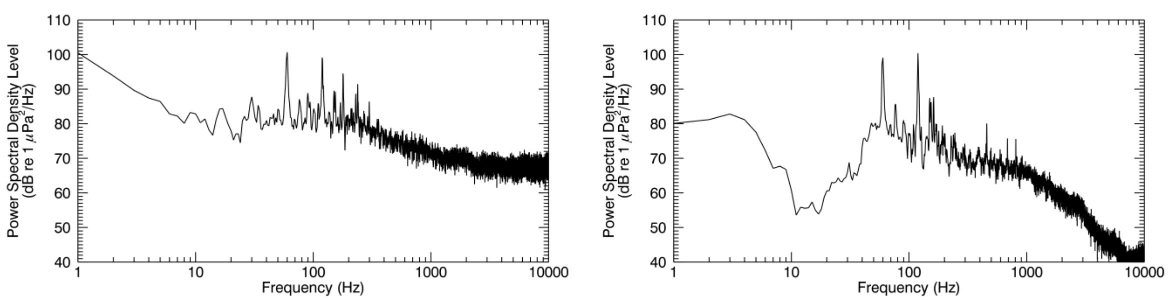


Figure 32. Average power spectral density (PSD) of the *Resolution* transiting at 5.5 kts from average of ten 1 s Hanning-windowed spectra centered at 14.3 m (left) and centered at 664 m (right) distance.

3.1.6. Margarita

SPLs were computed for the propeller driven *Margarita*'s vessel noise during its transit along SSC Track 2 from the closest point of approach (CPA) to the end of the track. This section of SSC Track 2 was selected as most representative of the vessel noise characteristics in terms of signal quality and consistency. The water depth along the track (from cartographic records) ranges between 12.8 m and 13.4 m. The continuous noise levels were computed after low-pass filtering at 10 kHz in consecutive 1-second time windows, a standard processing step that eliminates potential contribution from high frequency non-vessel sounds. Figure 33 shows the rms SPL levels versus time for the *Margarita* transiting at 7.7 kts, while Figure 34 presents the sound pressure levels versus range, with the best-fit and 90th percentile trend lines. To achieve the most accurate fits, data were analyzed in two sections: near-range (15 to 300 m), and far-range (300 to 3030 m). Data presented in the Figure 34 plots were recorded from the higher sensitivity TC4032 hydrophone. The ranges to the sound level thresholds of 160 to 120 dB re 1 µPa (rms) for the *Margarita* traveling at 7.7 kts are listed in Table 11. The vessel appears as a distributed sound source rather than a point at shorter ranges; therefore, radii smaller than about 20 m should be only considered notional (see Section 3.1.5). Figure 35 shows the spectrograms for the closest two OBHs, and Figure 36 shows the corresponding power spectra at CPA.

The *Resolution* and the *Margarita* have the same hull design; however, the *Resolution* is a jetboat, which influences the sound signature in both magnitude and structure. The *Margarita* has a definitive Lloyd mirror type pattern (Figure 35) when compared to the *Resolution* (Figure 31), due to cavitation of the propeller and the vessel propulsion system.

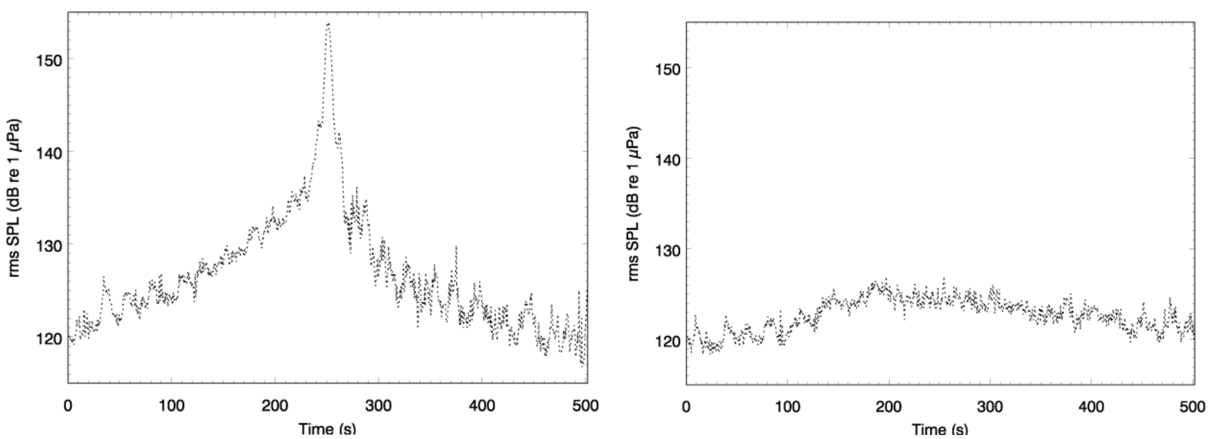


Figure 33. *Margarita* rms SPL versus time, in 1 s intervals while transiting at 7.7 kts measured by OBH A2 with a 15.5 m CPA (left) and by B2 with a 660 m CPA (right).

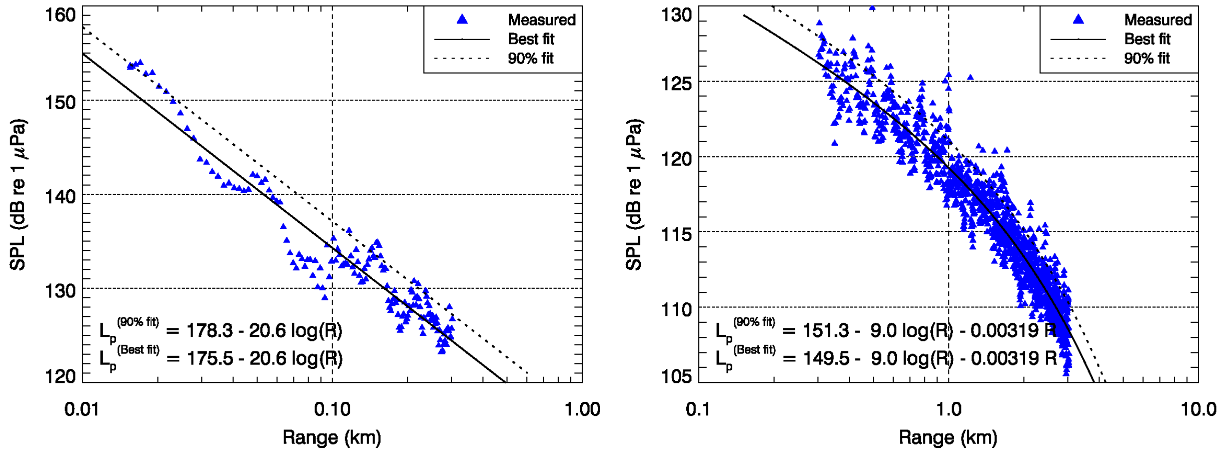


Figure 34. Sound pressure level (rms) versus slant range produced by the *Margarita* while it transited by OBH A2 at 7.7 kts outside the barrier islands. (left) Fit for 160–130 dB re 1 µPa, based only on measurements between 15 and 300 m range, (right) Fit for 120 dB re 1 µPa, based on measurements 300 to 3030 m. Solid line is the best-fit line to SPL data. Dashed line is the best-fit adjusted to exceed 90% of the SPL data.

Table 11. Threshold radii for the *Margarita* transiting at 7.7 kts at the SSC site, as determined from function fit to SPL versus distance data in Figure 34.

Threshold (dB re 1 µPa)	Best-Fit Line Radius (m)	90th Percentile Radius (m)
160	6*	8*
150	17	24
140	53	73
130	162	222
120	889	1151

*Extrapolated from minimum measurement range of 15.5 m. These distances are well inside the near-field of such a distributed source, and should be considered only as notional values.

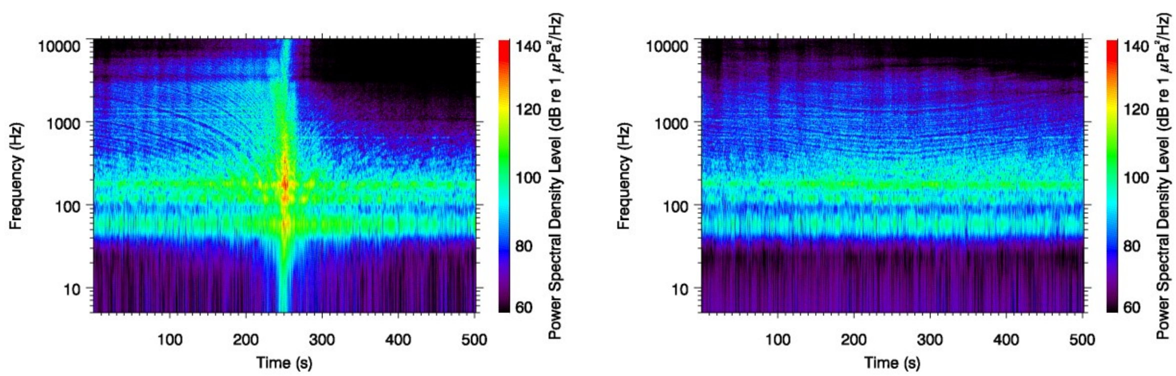


Figure 35. Spectrograms of the *Margarita* transiting at an average of 7.7 kts, (left) from 1000 m either side of A2, with a CPA of 15.5 m, and (right) for the same interval from B2, with a CPA of 660 m. 8192-pt FFT, 96 kHz sample rate, Hanning window, 87.5% overlap.

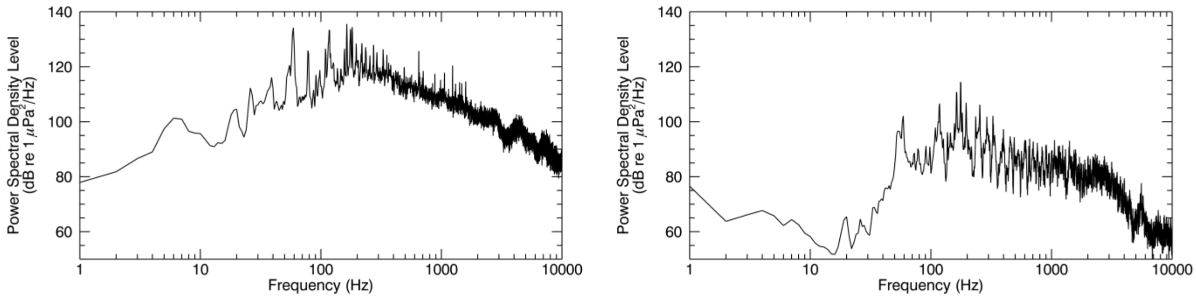


Figure 36. Average power spectral density (PSD) of the *Margarita* transiting at 7.7 kts from average of ten 1 s Hanning-windowed spectra centered at 15.5 m (left) and centered at 660 m (right) distance.

3.2. SSV/SSC Inside Barrier Islands

All airgun configuration trials inside the barrier islands were towed at 1 meter, the planned operational depth. Recorders were approximately placed at the 190, 180, and 160 dB isopleths in the across-track (broadside) direction as estimated in pre-season modeling. Because no direct broadside measurements were made near the 120 dB isopleth, the analysis was based on data extrapolated from curves fitted to the measured data to determine the range at this level.

3.2.1. Sound Speed Profiles

The sound speed profile was measured in one location inside the barrier islands (Figure 37). The profile has a faster near-surface speed of nearly 1470 m/s above approximately 1 m, a decreasing speed as the depth increases from 1 and 2 m, and a constant speed of nearly 1441 m/s below 2m. This profile induces a downward refracting propagation regime.

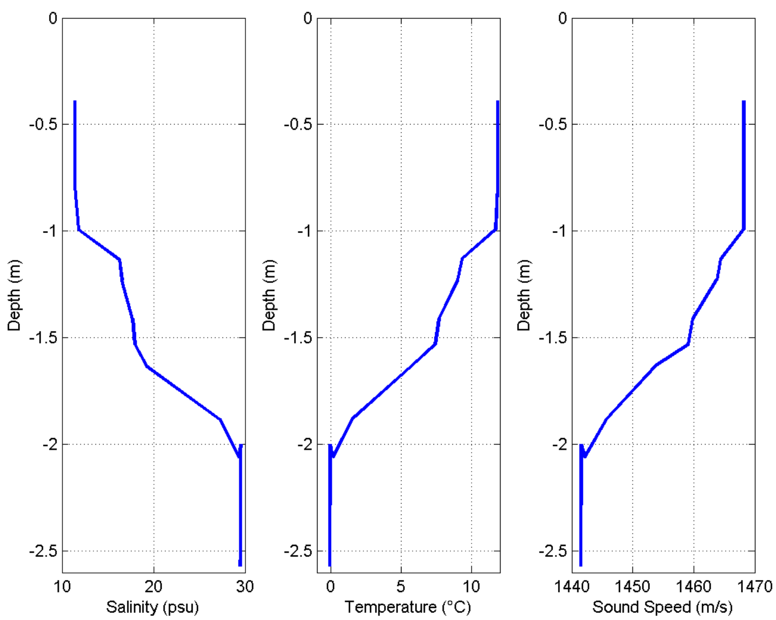


Figure 37. (left) Salinity, (center) temperature, and (right) sound speed profiles from CTD Cast 3 at 00:19:12 AKDT, 27 Jul 2012 at 70°32.114' N, 149°44.397' W, inside the barrier islands.

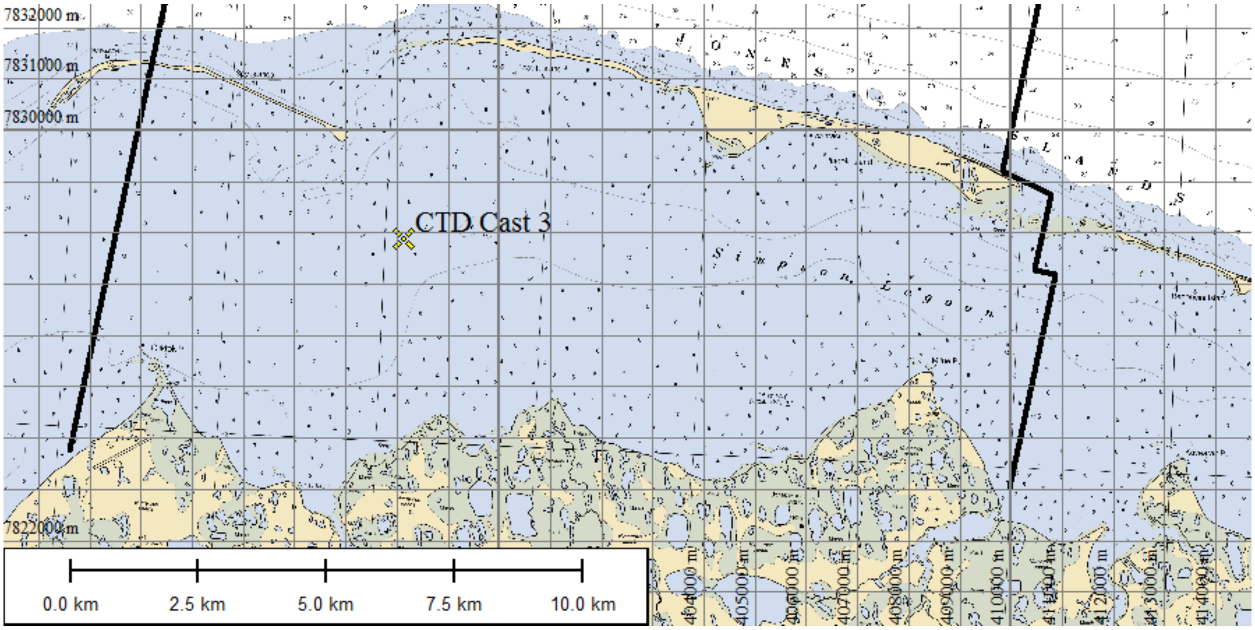


Figure 38. Sound speed profile measurement location, inside barrier islands.

3.2.2. 320 in^3 Airgun Array

Peak SPL, 90% rms SPL, and SEL for each shot were computed from acoustic data recorded on OBHs A1-C1. Figure 39 shows sound levels from the 320 in³ airgun versus slant range measured in the endfire and broadside directions for SSV Track 1. The closest broadside measurements, from OBH A1 were included in the endfire calculations. Tables 12 and 13 list ranges to various rms SPL thresholds for each of the fits in Figure 39. Figures 42 and 43 show the spectrograms for the endfire and broadside orientations; Figures 45 and 46 show the waveform and spectra.

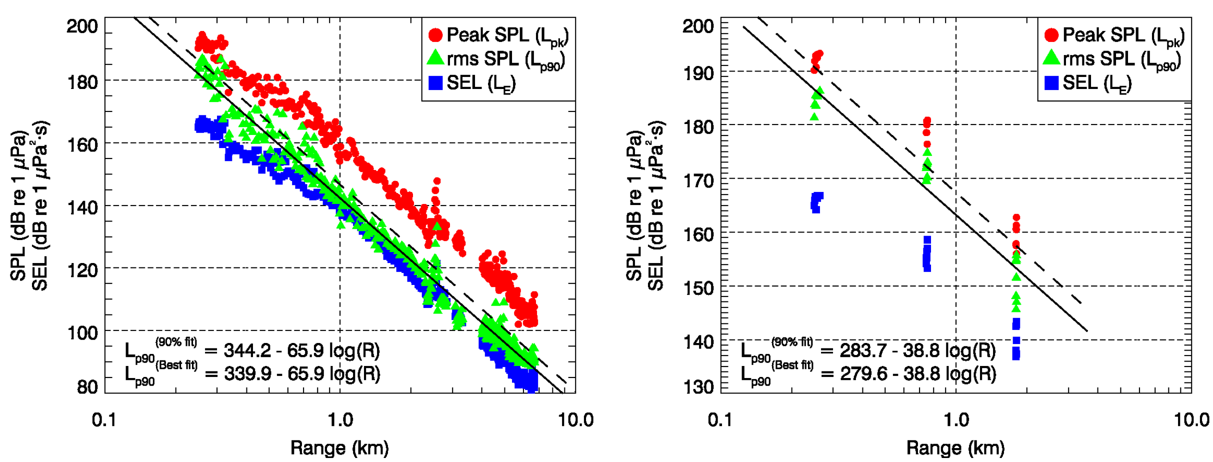


Figure 39. Peak SPL, rms SPL, and sound exposure level (SEL) versus slant range for the 320 in^3 airgun pulses in the (left) endfire and (right) broadside directions, inside the barrier islands. Solid line is the best-fit function to the 90% rms SPL. Dashed line is the best-fit adjusted to exceed 90% of the 90% rms SPL.

We examined the time series data for the approach of the 320 in^3 airgun array to OBH A1 (Figure 40) to determine what caused an the propagation of raised levels between 2304–2392 s into the file which captured the approach, corresponding to approximately 2.5 km (Figure 41) from the CPA. Spectrograms of four pulses in this section were also examined (Figure 42). These were investigated from the endfire direction (Figure 42); we determined that they are due to a propagation artifact that allows for better transmission of the waterborne sound above 200 Hz. This artifact only occurs when the vessel is in a particular section of the track and therefore is potentially due to bathymetric conditions not shown on the available charts. Due to the limited number of data points that relate to this event, and therefore the minimal impact, the radii calculated have not been re-adjusted to account for their removal.

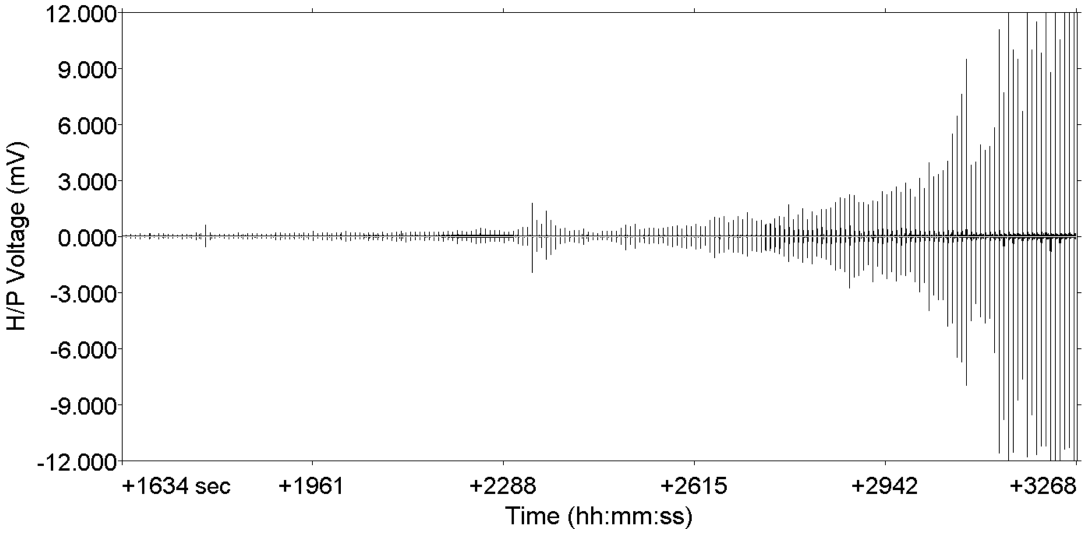


Figure 40. Time series representation of 320 in³ airgun pulses in the endfire direction showing approach and CPA of airgun on Channel 0 of OBH A1.

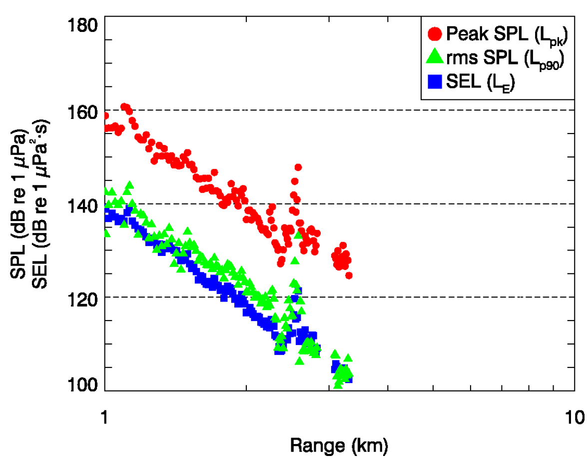


Figure 41. Peak SPL, rms SPL, and sound exposure level (SEL) versus slant range for the 320 in^3 airgun pulses in the endfire direction inside barrier islands ranging from 1–3.5 km.

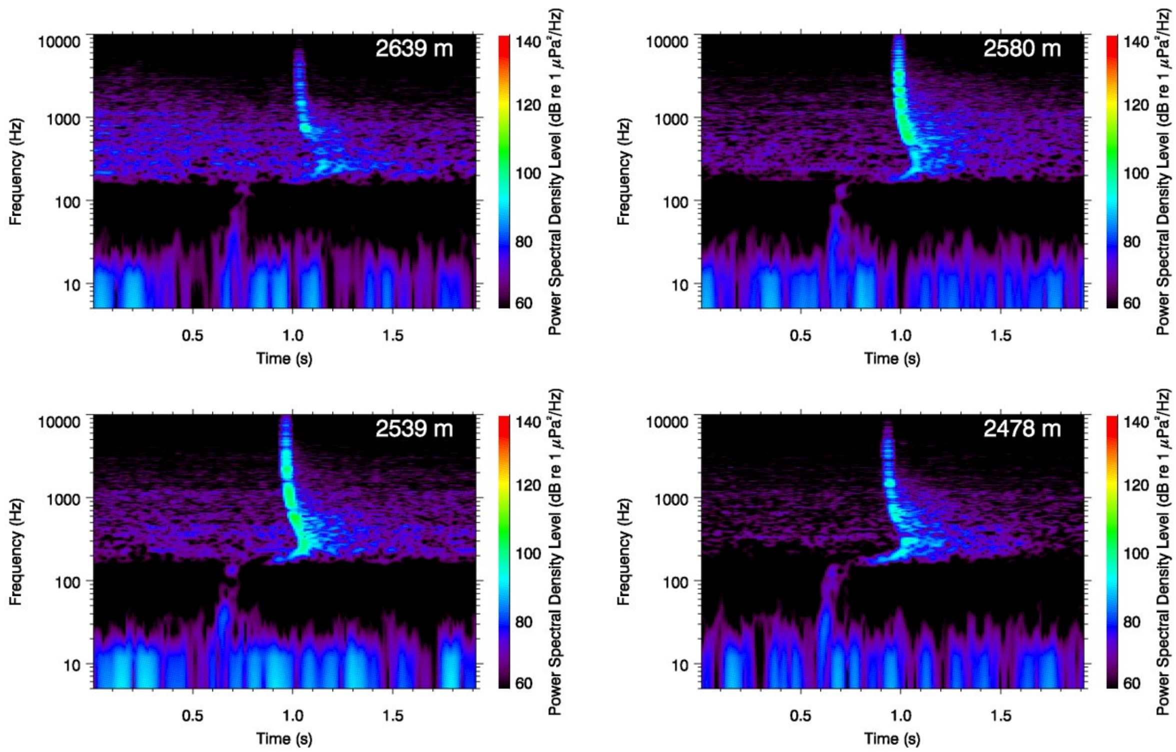


Figure 42. *Endfire*: Spectrograms of airgun pulses from the 320 in³ airgun array investigating section of raised levels: (top left) before raised section (2639 m, 2304 s into file), (top right) start of raised section (2580 m, 2336 s into file), (bottom left) toward end of raised section (2539 m, 2360 s into file), and (bottom right) after raised section (2478 m, 2392 s into file); 8192-pt FFT, 96 kHz sample rate, Hanning window, 87.5% overlap.

Table 12. *Endfire*: Threshold radii for the 320 in^3 airgun array, inside barrier islands as determined from best-fit lines to 90% rms SPL versus distance data in Figure 39.

Endfire Distance in meters (inside barrier islands)		
Threshold (dB re 1 μPa)	*Best-Fit*	*90th Percentile*
190	189	219
180	267	311
170	379	441
160	538	625
120	2177	2528

Table 13. *Broadside*: Threshold radii for the 320 in^3 airgun array, inside barrier islands as determined from best-fit lines to 90% rms SPL versus distance data in Figure 39.

Broadside Distance in meters (inside barrier islands)		
Threshold (dB re 1 µPa)	*Best-Fit*	*90th Percentile*
190	203	260
180	368	472
170	667	854
160	1207	1545
120	12 964	16 598

Figure 43 and Figure 44 show pulse spectrograms from measurements taken at strategic locations along the track line. The closest broadside measurement, from OBH A1, was close to the 190 dB modeled threshold radius of 160 m (Figure 44, broadside range 249 m). The other measurements are distributed along the track line to provide indication of the pulse shape as the distance increases. The other two broadside CPA's, perpendicular to the array axis, occurred at 746 m from B1 and 1796 m from C1, with the measurement at C1 being the closest to the 160 dB modeled threshold of 1500 m.

These measurements indicate strong water and substrate propagation within 1000 m, including the 190 and 180 dB distances, this feature is observable through the frequency range of the detected pulse (1 Hz to 10 kHz). By the time the modeled 160 dB threshold distance is reached, the substrate propagation is noticeably less and the energy, having travelled in the higher sound speed bottom, has distinctively split from the waterborne component. The bottom-propagated energy below 150 Hz at 1796 m arrives 0.2 s before the main pulse.

The pulses at these ranges have a shorter 90% rms SPL length than the model predicted; partly because of this, we saw a greater than expected difference between the rms SPL and SEL levels. The measurement location closest to the 120 dB modeled threshold of 5700 m is 4016 m (Figure 43, endfire range), at which distance the pulse is barely distinguishable from the background noise. The actual length of this pulse (Figure 45) is greater than expected from the modeling, resulting in a smaller difference between the rms SPL and SEL level that contributes to a smaller threshold radius than predicted.

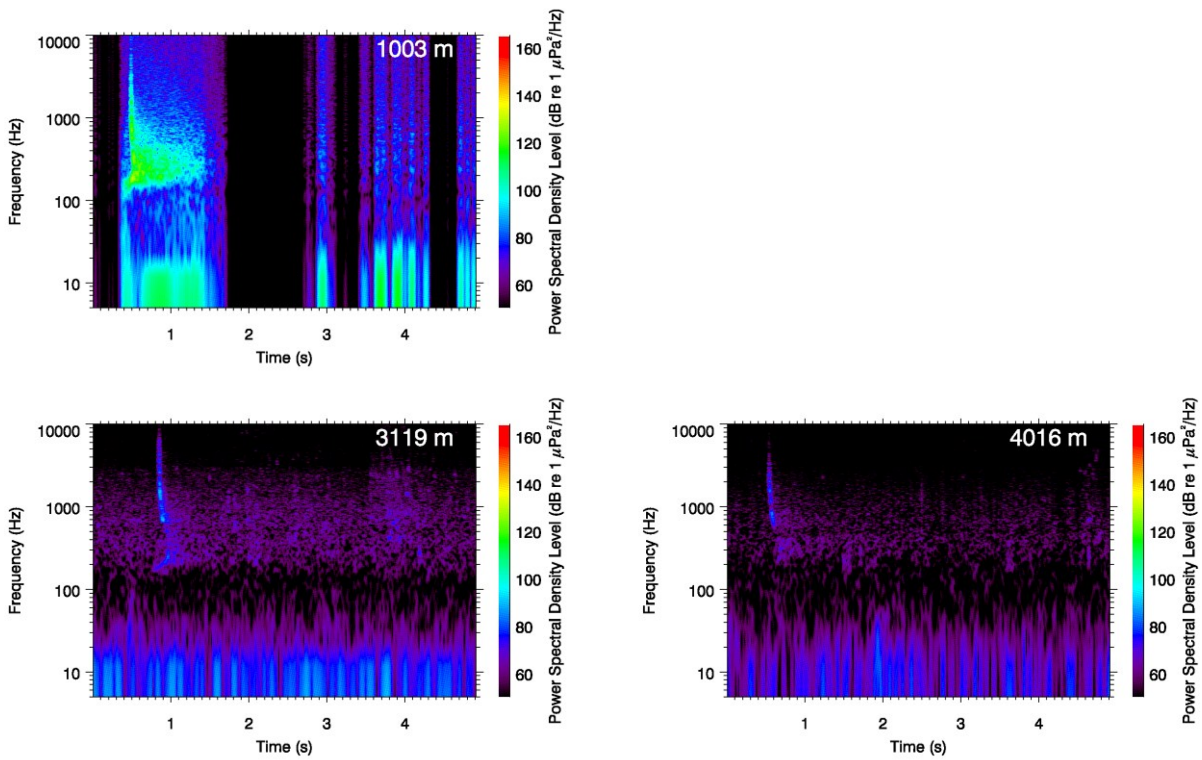


Figure 43. *Endfire*: Spectrograms of airgun pulses from the 320 in³ airgun array at three distances from OBH A1, 1003 m, 3119 m and 4016 m; 8192-pt FFT, 96 kHz sample rate, Hanning window, 87.5% overlap.

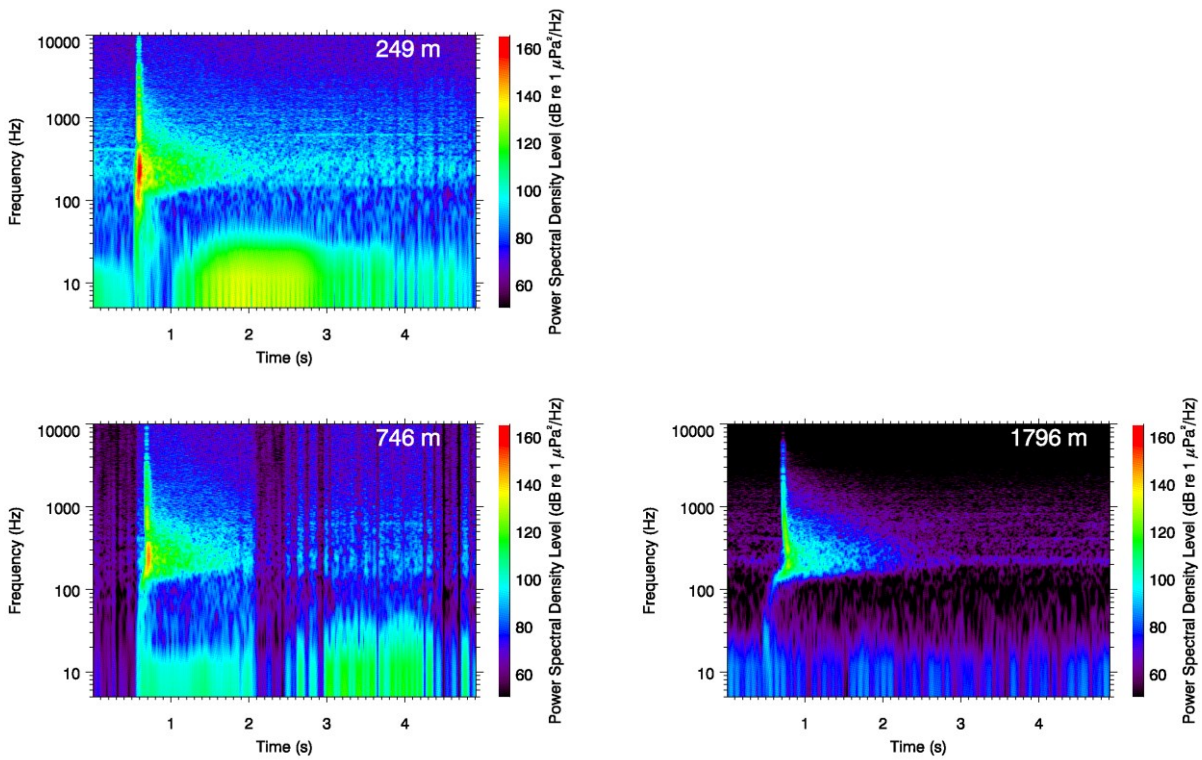


Figure 44. *Broadside*: Spectrograms of airgun pulses from the 320 in³ airgun array at the CPA to each OBH, 249 m to A1, 746 m to B1, 1796 m to C1; 8192-pt FFT, 96 kHz sample rate, Hanning window, 87.5% overlap.

The SEL spectral density of the pulses (Figures 45 and 46) show the contribution of low frequency ambient noise in the shallow environment. Within 1796 m, the main contribution to the pulse energy is between 100 and 1000 Hz; however, as the distance increases, the pulses become restricted to between 500 Hz and 4 000 Hz.

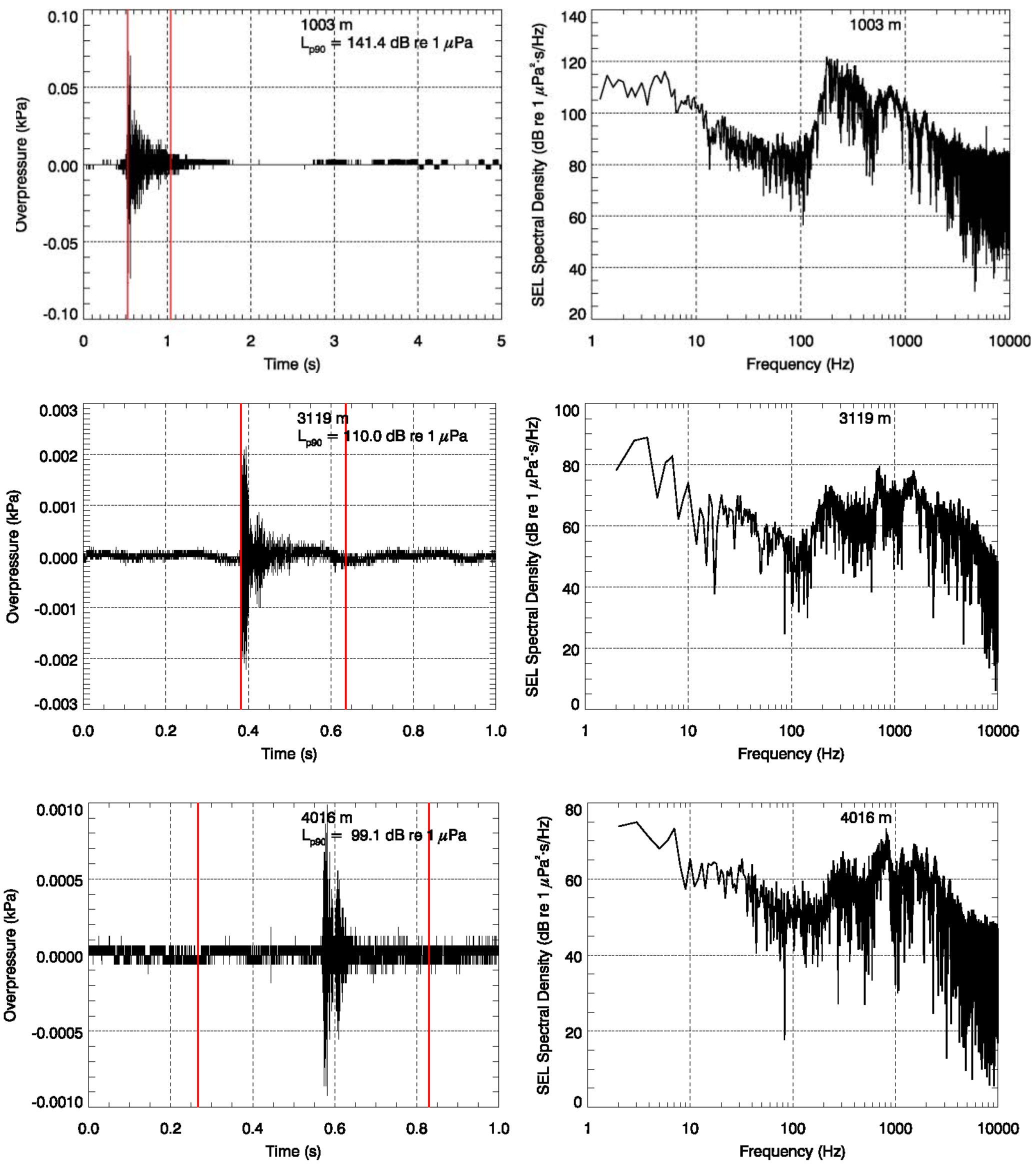


Figure 45. *Endfire*: (left) Waveform and spectra (right) corresponding SEL spectral density of 320 in³ airgun array pulses at three distances from OBH A1, 1003 m, 3119 m, and 4016 m. The red bars on the waveform indicate the 90% energy pulse duration.

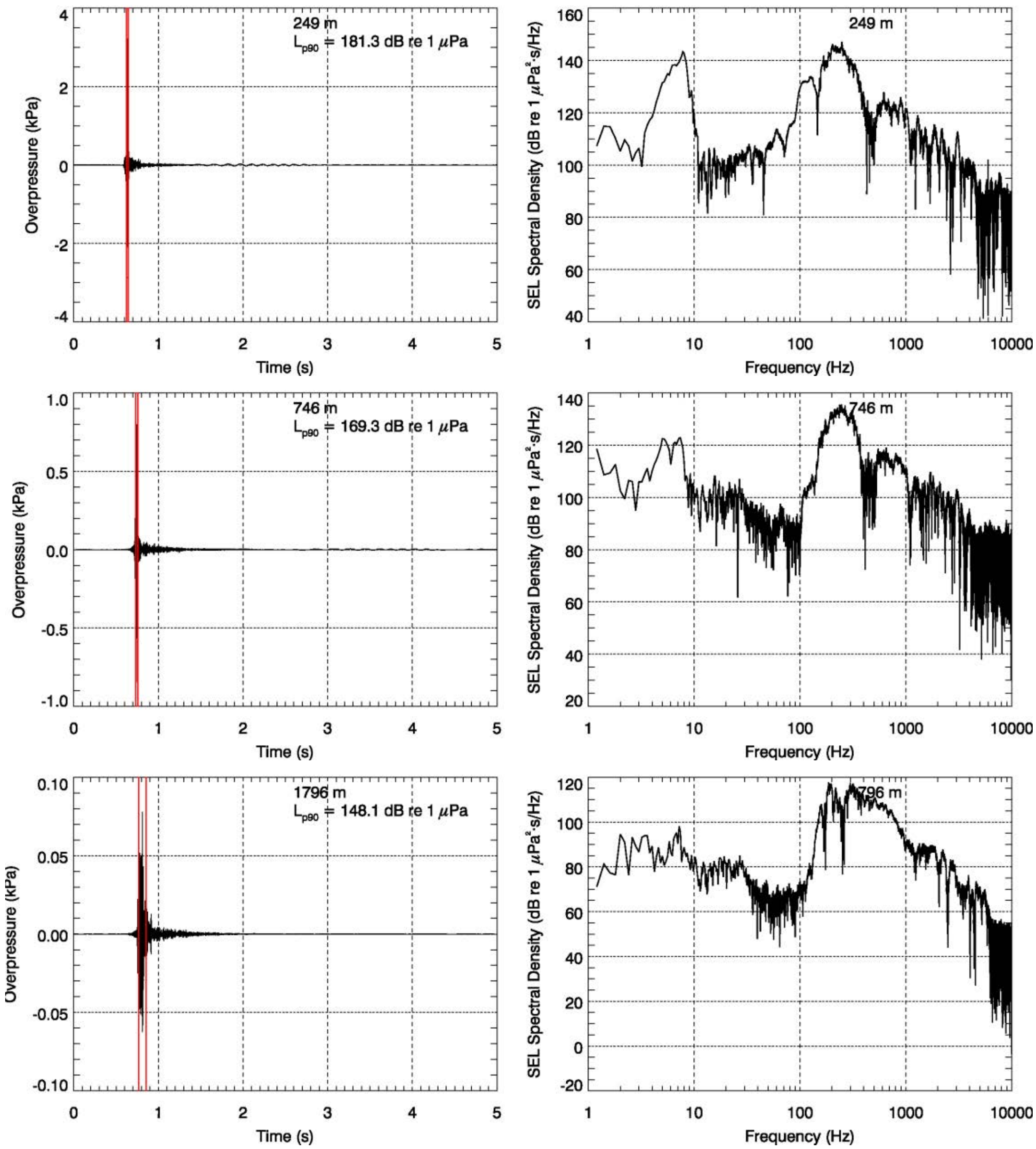


Figure 46. *Broadside*: (left) Waveform and spectra (right) corresponding SEL spectral density of 320 in³ airgun array pulses at the CPA to each OBH, 249 m to A1, 746 m to B2, 1796 m to C2. The red bars on the waveform indicate the 90% energy pulse duration.

3.2.3. 40 in^3 Mitigation Airgun

Peak SPL, 90% rms SPL, and SEL for each shot were computed from acoustic data recorded on OBHs A1–C1. Figure 47 shows sound levels from the 40 in³ mitigation airgun versus slant range measured for SSV Track 1. The closest broadside measurements, from OBH A1 were included in the endfire calculations. Table 14 lists ranges to various rms SPL thresholds for each of the fits in Figure 47. The endfire and broadside results presented do not have any connection with source directionality, as the source is omnidirectional, and the different levels at matching distances are only an effect of the propagation environment. Figures 48 and 49 show the spectrograms for the endfire and broadside orientations; Figures 50 and 51 show the waveform and spectra.

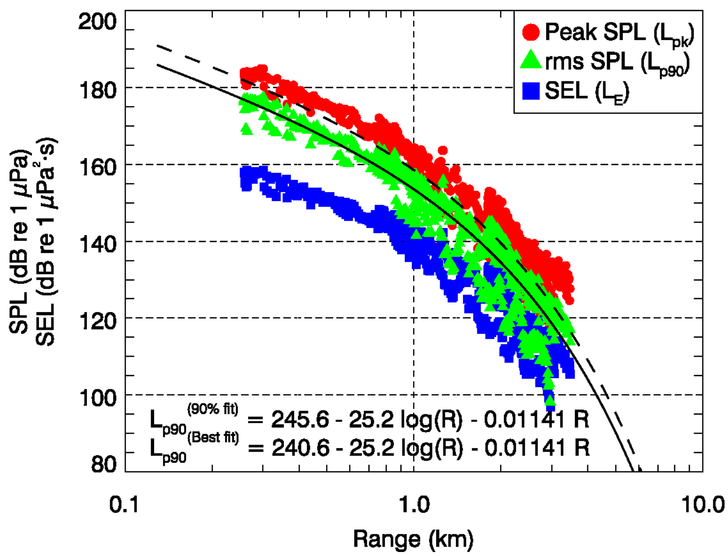


Figure 47. Peak SPL, rms SPL, and sound exposure level (SEL) versus slant range for the 40 in^3 mitigation airgun pulses in the endfire direction, inside the barrier islands. Solid line is the best-fit line to the 90% rms SPL. Dashed line is the best-fit adjusted to exceed 90% of the 90% rms SPL.

Table 14. Threshold radii for the 40 in^3 mitigation airgun, inside barrier islands as determined from best-fit lines to 90% rms SPL versus distance data in Figure 47.

Distance in meters (inside barrier islands)		
Threshold (dB re 1 μPa)	*Best-Fit*	*90th Percentile*
190	92	138
180	203	293
170	409	555
160	729	933
120	2907	3242

The requirement to measure the 320 in^3 airgun with the same OBH deployment inside the barrier islands as the 40 in^3 led to the OBHs being placed at ranges more suitable to measure the 180 and 190 dB thresholds associated with the 320 in^3 airgun. Therefore the closest OBH was A1 in the broadside direction at 258 m (Figure 49), which is 199 m further away than the predicted 180 dB threshold distance, however after analysis it was determined to be close to the 90th percentile measured distance. Figures 48 (endfire 897 m) and 49 (broadside 757 m) show pulse spectrograms from measurements taken at ranges just past the 160 dB modeled threshold radius of 700 m. The broadside range of 757 m is the CPA range for OBH B1, deployed at that lateral offset perpendicular to the array tow path, and the closest point to the 160 dB modeled threshold radius.

These measurements indicate good water propagation at the 180 dB distances, observable through the frequency range of the detected pulse (70 Hz to 8 kHz). The substrate borne low frequency component of the pulse does not propagate well, and is only faintly visible at the 160 dB distance.

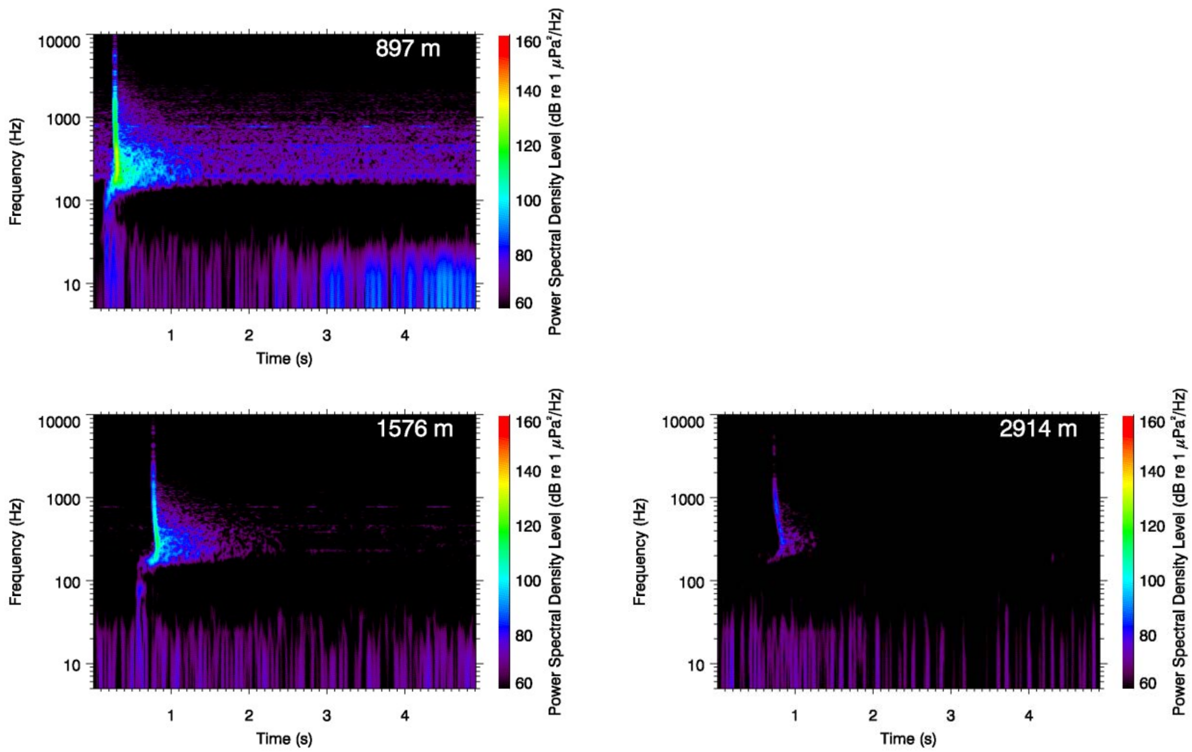


Figure 48. *Endfire*: Spectrograms of airgun pulses from the 40 in^3 mitigation airgun at three distances to OBH A1, 897 m, 1576 m and 2914 m; 8192-pt FFT, 96 kHz sample rate, Hanning window, 87.5% overlap. Endfire only specified to differentiate measurement orientation.

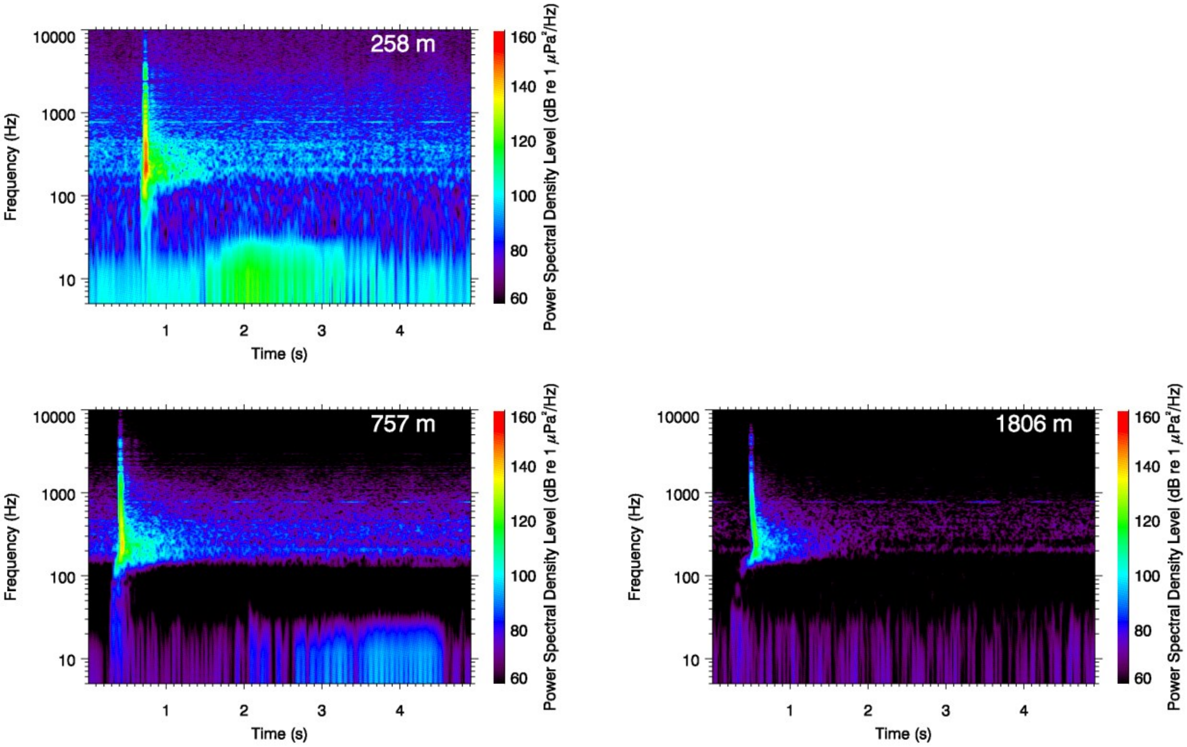


Figure 49. *Broadside*: Spectrograms of airgun pulses from the 40 in^3 mitigation airgun at the CPA to each OBH, 258 m to A1, 757 m to B1, 1806 m to C1; 8192-pt FFT, 96 kHz sample rate, Hanning window, 87.5% overlap. Broadside only specified to differentiate measurement orientation.

Comparing the endfire and broadband recorded pulse structures at reasonably equivalent ranges (Figure 50, endfire range 1576 m, and Figure 51, broadside range 1806 m) demonstrated the received pulses have similar structures, but are different in received levels by approximately 10 dB. The 40 in^3 mitigation airgun is omnidirectional at the source; therefore, the different received levels are caused by propagation effects, a main contributor would be the sound speed profile combined with the increasing depth in the broadside direction.

The pulse spectrums shown in these figures highlight significant features below 10 Hz. This is most likely due to wind and flow noise in the shallow water environment of the OBH;which varies between locations and times due to wind and current variations. The spectrum also sharply attenuates between 200 and 100 Hz, which is expected for shallow water environments, and only one mode of the pulse propagates.

The measurement location close to the 120 dB modeled threshold (Figure 50, endfire range 2 914 m), shows the pulse as being extremely faint, and close to background noise levels.

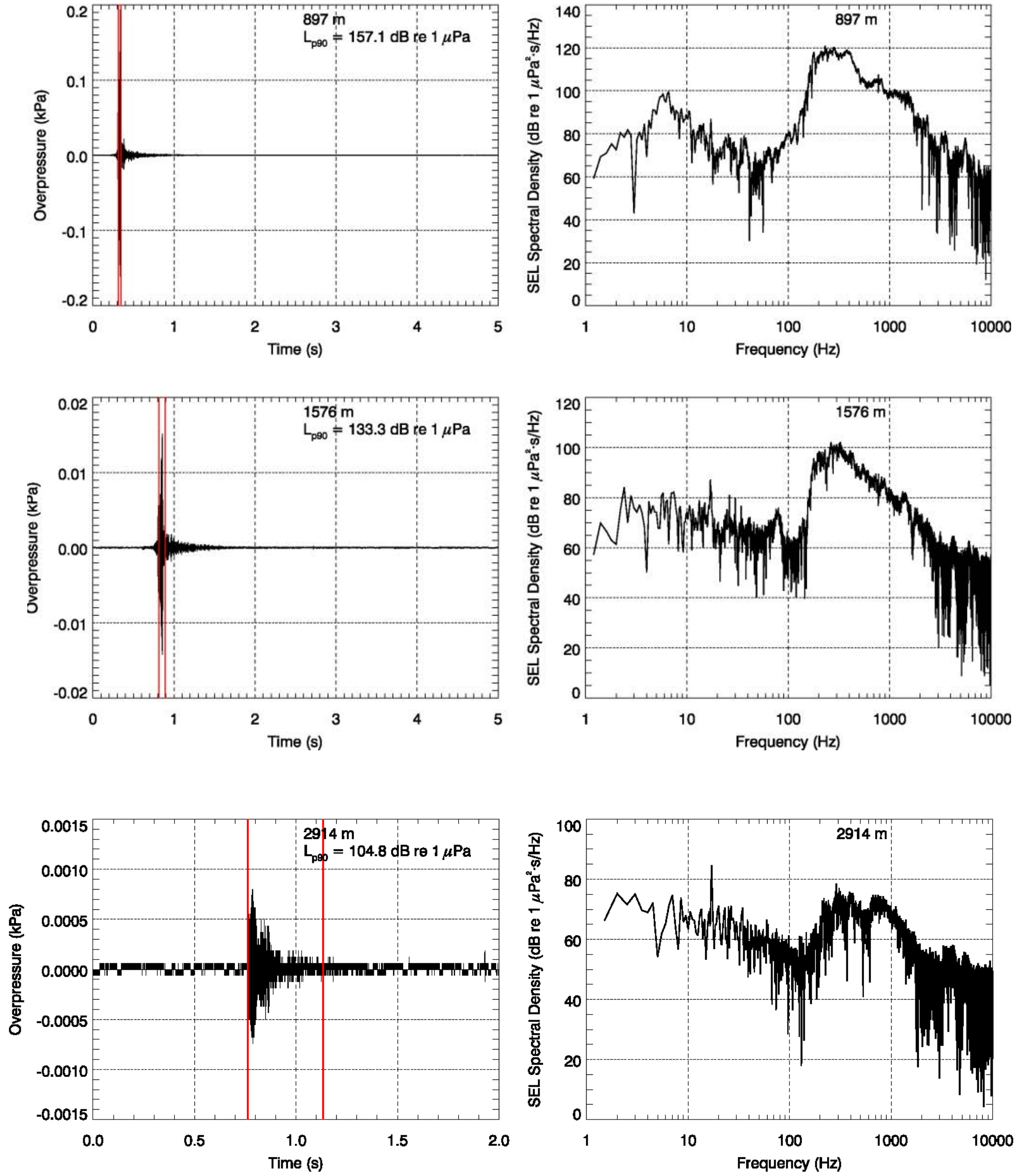


Figure 50. Endfire: (left) Waveform and spectra (right) corresponding SEL spectral density of 40 in³ mitigation airgun pulses at three distances to OBH A1, 897 m, 1576 m and 2914 m. The red bars on the waveform indicate the 90% energy pulse duration. Endfire only specified to differentiate measurement orientation.

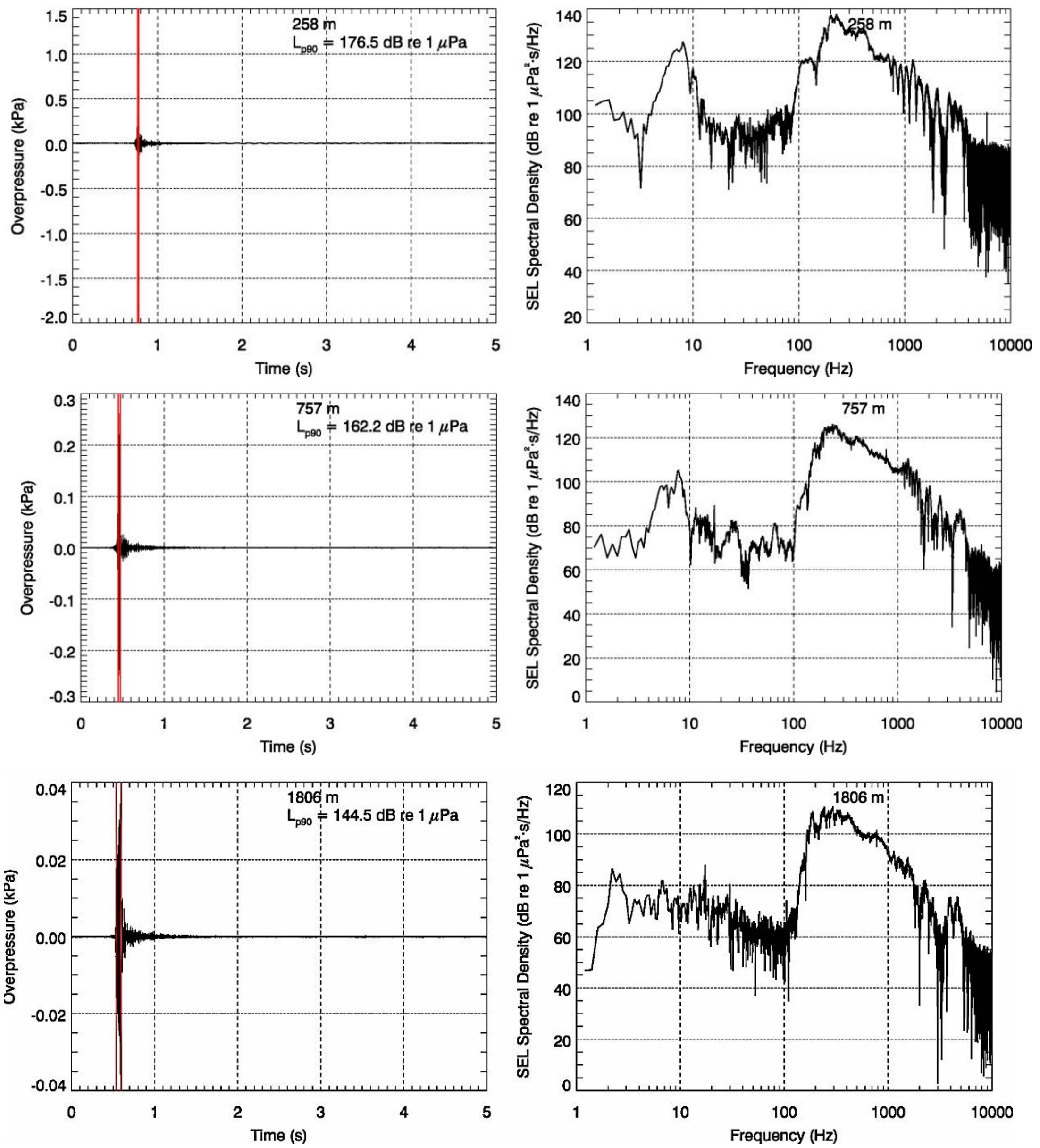


Figure 51. *Broadside*: (left) Waveform and spectra (right) corresponding SEL spectral density of 40 in³ mitigation airgun pulses at the CPA to each OBH, 258 m to A1, 757 m to B1, 1806 m to C1. The red bars on the waveform indicate the 90% energy pulse duration. Broadside only specified to differentiate measurement orientation.

3.2.4. Storm Warning

SPLs were computed for the *Storm Warning*'s vessel noise during its transit along SSC Track 1 from the closest point of approach (CPA) to the end of the track. This section of SSC Track 1 was selected as most representative of the vessel noise characteristics in terms of signal quality and consistency. The water depth along the track (from cartographic records) ranges between 1.8 m and 2.4 m. The continuous noise levels were computed after low-pass filtering at 10 kHz in consecutive 1-second time windows, a standard processing step that eliminates potential contribution from high frequency non-vessel sounds.

Figure 52 shows the rms SPL levels versus time for the *Storm Warning* transiting at 6.3 kts, Figures 53 and 54 presents the sound pressure levels versus range, with the best-fit and 90th percentile trend lines. To remove the surge of non-acoustic noise caused by the propulsion water jet, which occurred for a few meters astern of the hull in the extremely shallow water, we analyzed the acoustic data from the entire approach, but only analyzed acoustic data more than 60 m from the recorder. To achieve the most accurate fits, the approach data were analyzed from 1000 m to the CPA of 3 m, while the departure data were analyzed in two sections: near-range (60 to 300 m), and far-range (300 to 1000 m). Data presented in the Figure 54 plots were recorded from the higher sensitivity TC4032 hydrophone. The ranges to the sound level thresholds of 160 to 120 dB re 1 µPa (rms) for the *Storm Warning* traveling at 6.3 kts are listed in Table 15. The vessel appears as a distributed sound source rather than a point at shorter ranges; therefore, radii smaller than about 20 m should be only considered notional (see Section 3.1.5). Figure 55 shows the spectrograms for the closest two OBHs, and Figure 56 shows the corresponding power spectra at CPA.

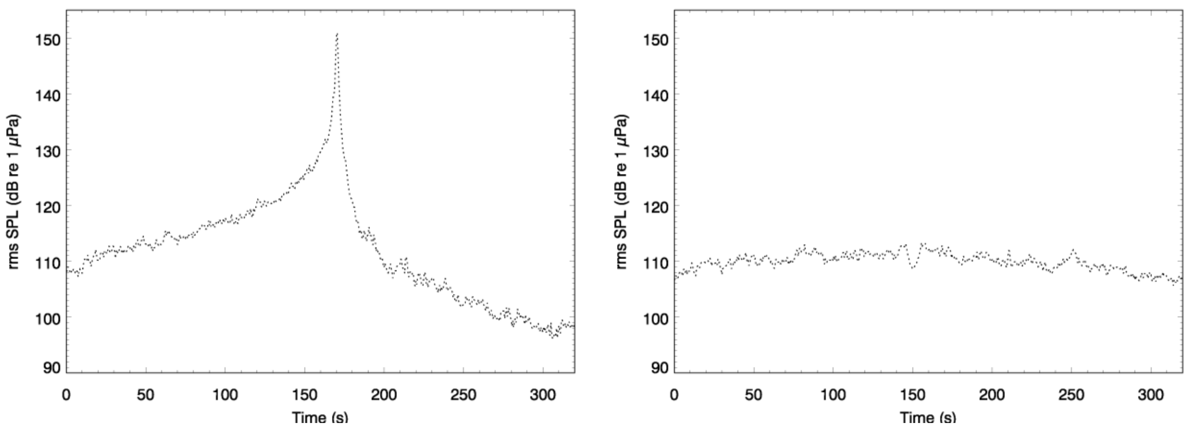


Figure 52. *Storm Warning* rms SPL versus time, in 1 s intervals while transiting at 6.3 kts measured by OBH A1 with a 3 m CPA (left) and OBH B1 with a 501 m CPA (right), inside barrier islands.

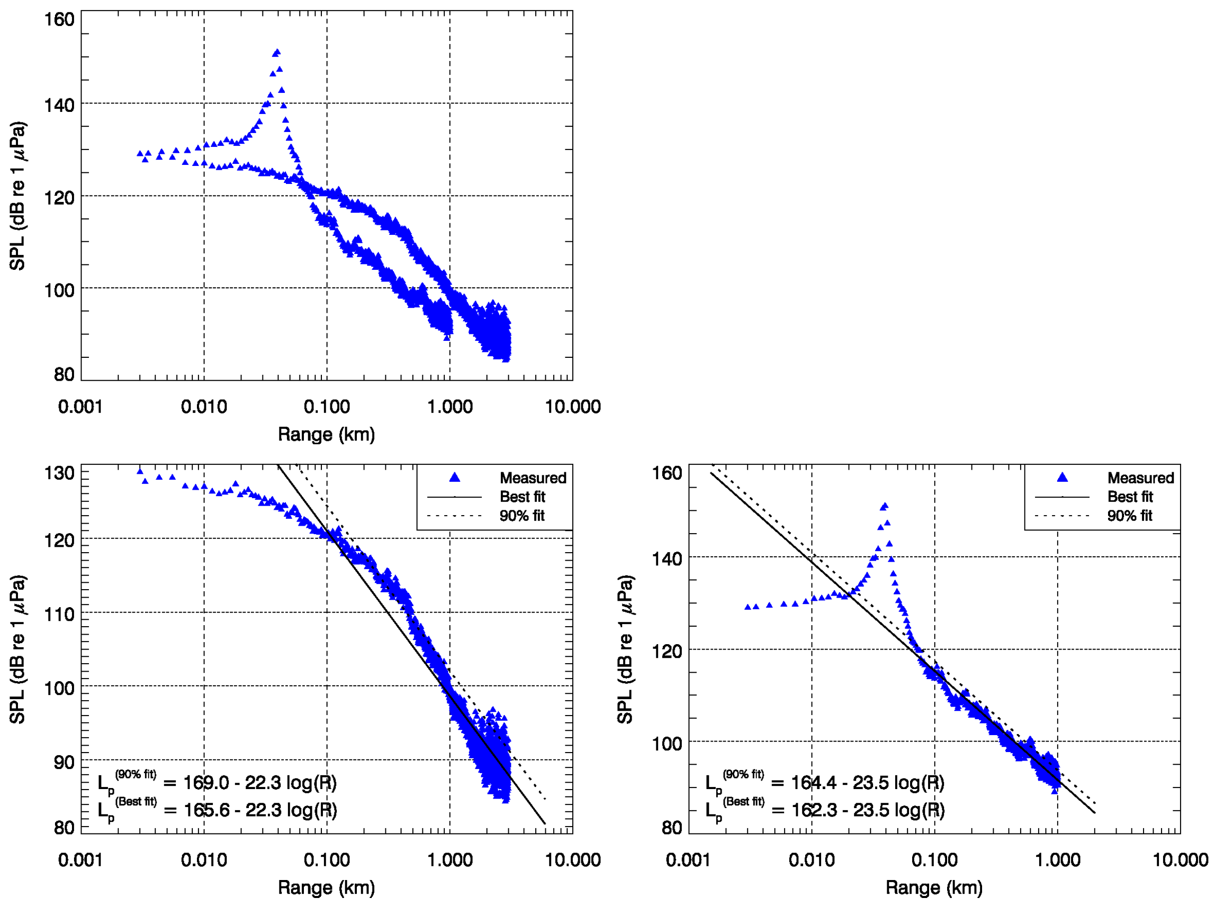


Figure 53. Sound pressure level (rms) versus slant range produced by the *Storm Warning* as it transited past OBH A1 at 6.3 kts inside the barrier islands (top left), showing both approach (bottom left) and departure (bottom right). These plots show the spurious acoustic effects during departure as opposed to approach, but were not used in the analysis.

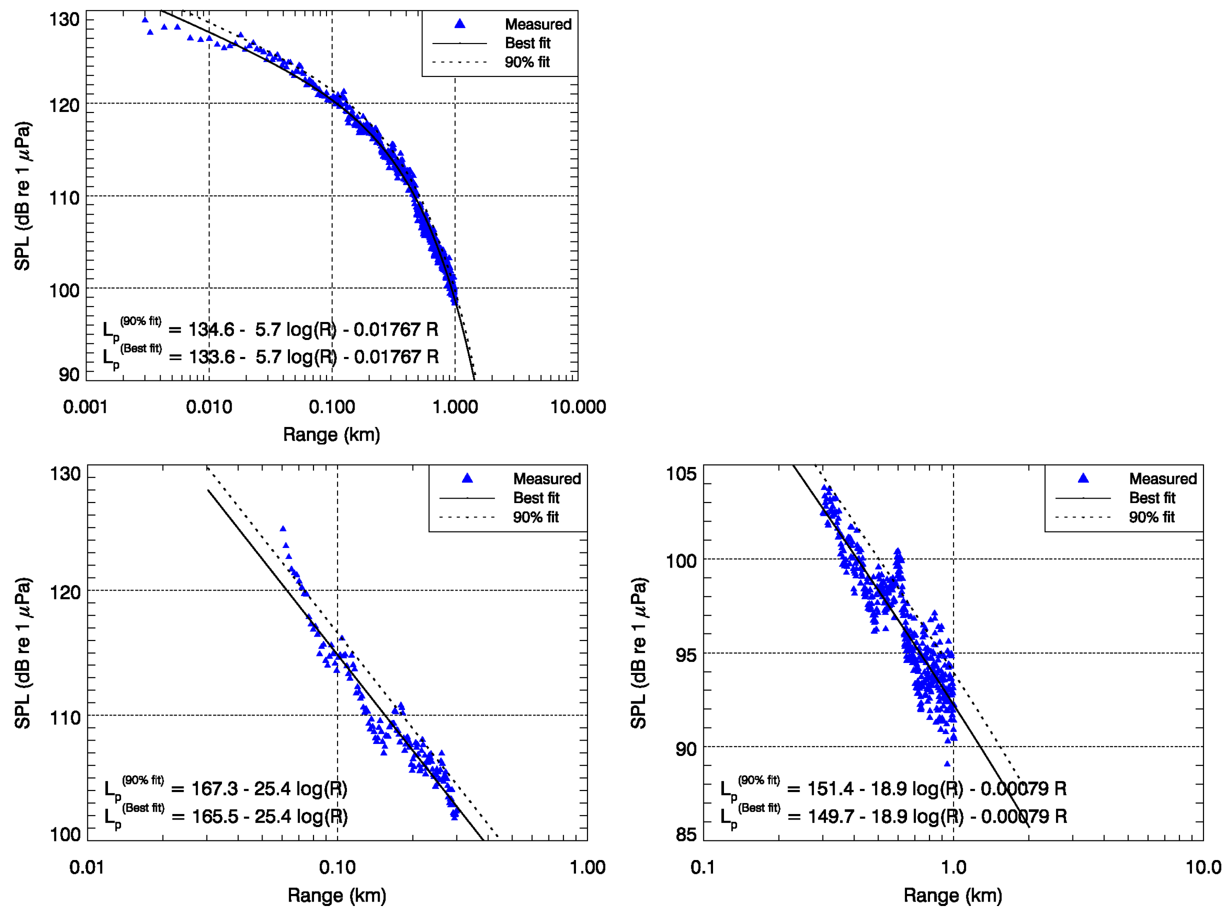


Figure 54. Sound pressure level (rms) versus slant range produced by the *Storm Warning* as it transited past OBH A1 at 6.3 kts inside the barrier islands.(top left) Fit for 130-120 dB re 1 µPa, based only on measurements between 1000 and 3 m range, approach (bottom left) fit for 160–130 dB re 1 µPa, based only on measurements between 60 and 300 m range, departure (right) fit for 120 dB re 1 µPa, based on measurements from 300 to 1000 m, departure. Solid line is the best-fit line to the SPLs. Dashed line is the best-fit adjusted to exceed 90% of the SPLs.

Table 15. Threshold radii for the *Storm Warning* transiting at 6.3 kts at the SSC site, as determined from function fit to SPL versus distance data in Figure 54.

	Approach		Departure	
Threshold (dB re 1 µPa)	*Best-Fit Line Radius (m)*	*90th Percentile Radius*	*Best-Fit Line Radius (m)*	*90th Percentile Radius*
160	-	-	2*	2*
150	-	-	4*	5*
140	-	-	10*	12*
130	4	6	25*	29*
120	106	134	37*	46*

*Extrapolated from a minimum measurement range of 60 m. Distances within 20 m are well inside the near-field of such a distributed source, and should be considered only as notional values.

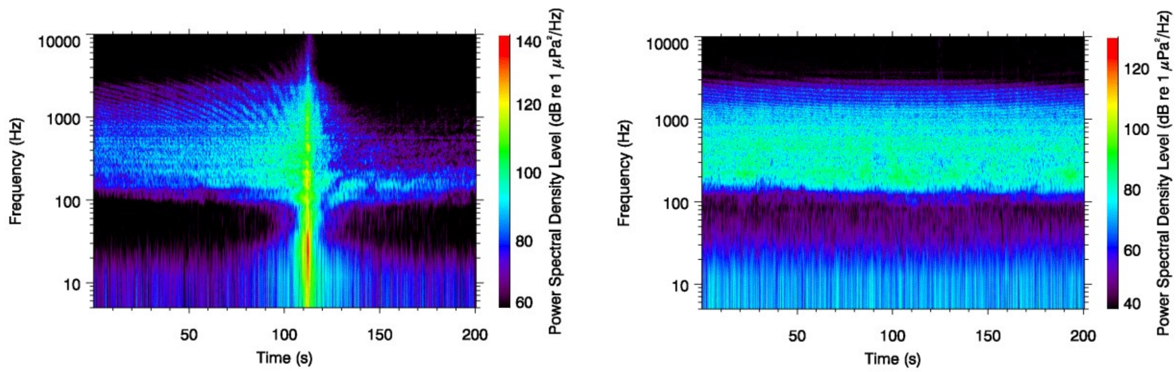


Figure 55. Spectrograms of the *Storm Warning* transiting at 6.3 kts, (left) past A1 with a CPA of 3 m, and (right) past B1 with a CPA of 501 m. 8192-pt FFT, 96 kHz sample rate, Hanning window, 87.5% overlap.

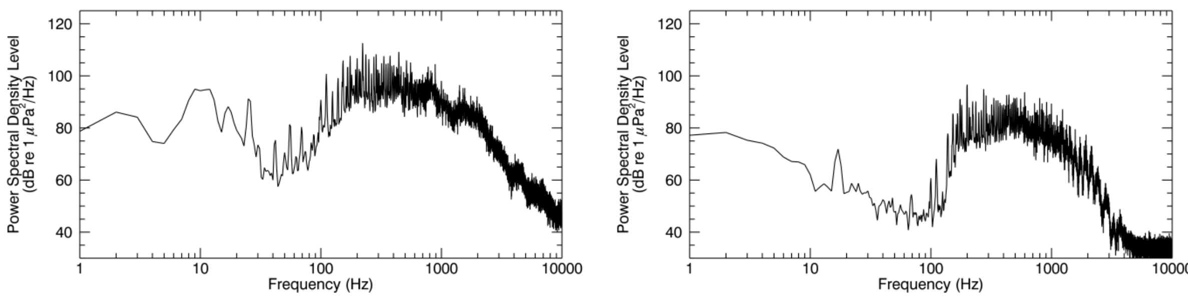


Figure 56. Average power spectral density (PSD) of the *Storm Warning* transiting at 6.3 kts from average of six 1 s Hanning-windowed spectra at centered at 3 m (left) and at 501 m (right) distance.

3.3. Long-Range Measurements: Dipping Hydrophone

The primary goal of the long-range measurements conducted with the dipping hydrophone system was to determine, at discrete times during the seismic survey after 25 August, the airgun pulse levels received outside the barrier islands. The aim was to compare these values to the predicted long-range values from the SSV analysis.

The positional data for the vessels when airguns were active was provided through shot log files (.sps) provided by CGGVeritas. Positional data was only recorded when the main arrays (640 and 320 in^3) were operational, therefore no location data were available for the 40 in^3 mitigation airgun.

No seismic pulses were detected in the dipping hydrophone recordings. Table 16 lists the parameters of each dipping hydrophone recordings and Figures 57–60 show the location of the airgun arrays and dipping hydrophone.

Two examples of the dipping hydrophone recordings are shown in Figures 78 and 81, which show ambient noise and vessel noise respectively. A comparison of the periods measured by the dipping hydrophone and long-term AMARs was conducted (Section 4.4), which verify the levels recorded by the system.

Table 16. Summary of long-range measurements. *Resolution* and *Margarita* were active; *Storm Warning* was inactive. See Table 3 for the recording dates and times, starting locations, and water depths.

Rec No.	Type of signal detected	Distance to source (km)		Source-receiver path blocked by a barrier island	
		Margarita (320 in^3)	*Resolution* (320 in^3)	*Margarita* (320 in^3)	*Resolution* (320 in^3)
1	-*	8.7–9.7	N/A**	No	Yes
2	-	8.1–8.9	9.9-10.3	Yes	Yes
3	-	7.6–8.7	4.9-6.2	Yes	Yes
4	Vessel self-noise	10.3–11.0	4.4-5.6	No	Yes
5	Vessel self-noise	7.4–8.1	7.0-7.9	Yes	Yes
6	-	7.3–8.8	12.1-12.8	Yes	No
7	-	8.7–10.1	7.4-8.4	Yes	Yes
8	-	13.2–14.1	7.6-8.5	Yes	Yes

*The dipping hydrophone system was not functioning properly for this recording.
**Navigation logs indicated the *Resolution's* 40 in^3 mitigation gun was operating during this recording, but the navigation data did not include positional information for this source.

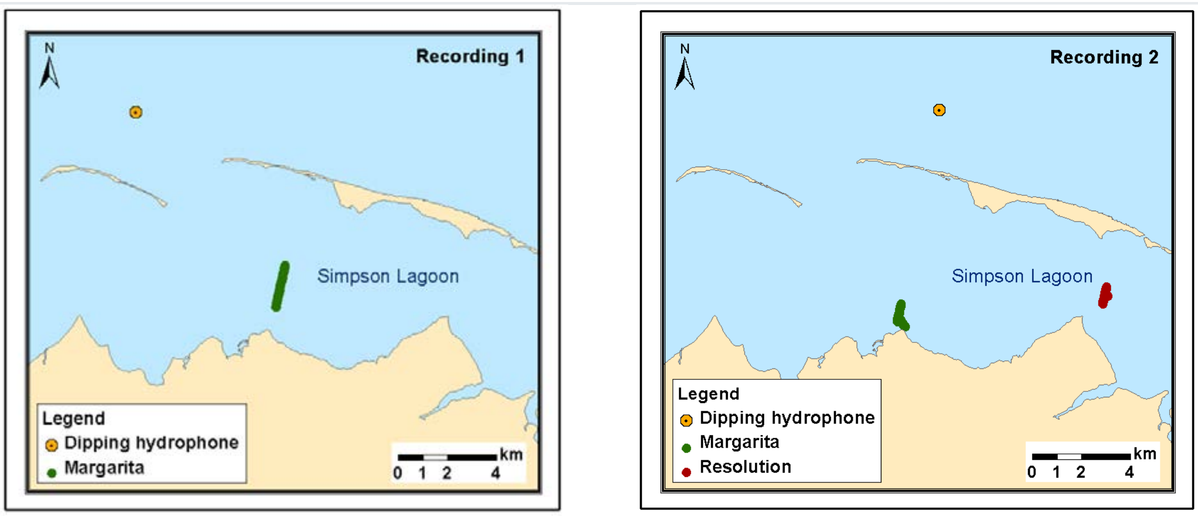


Figure 57. Locations of the *Margarita* and *Resolution* when the 320 in^3 arrays were operating during (left) Recording 1 and (right) Recording 2. The dipping hydrophone system did not function properly during Recording 1. The *Resolution's* 40 in^3 mitigation airgun was operating during Recording 1, but no positional data for that source was provided.

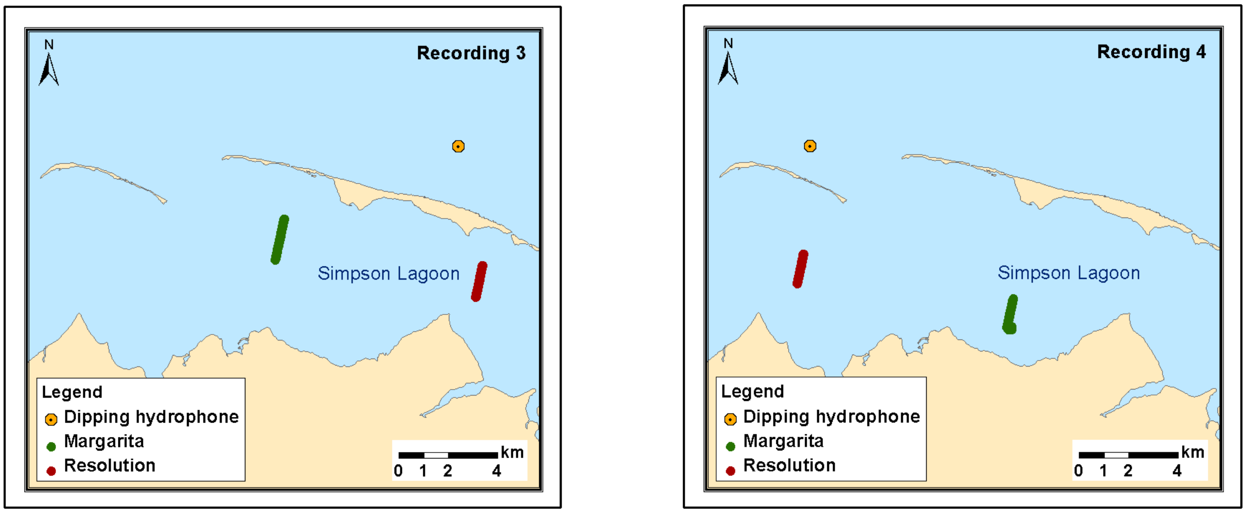


Figure 58. Locations of the *Margarita* and *Resolution* when the 320 in^3 arrays were operating during (left) Recording 3 and (right) Recording 4.

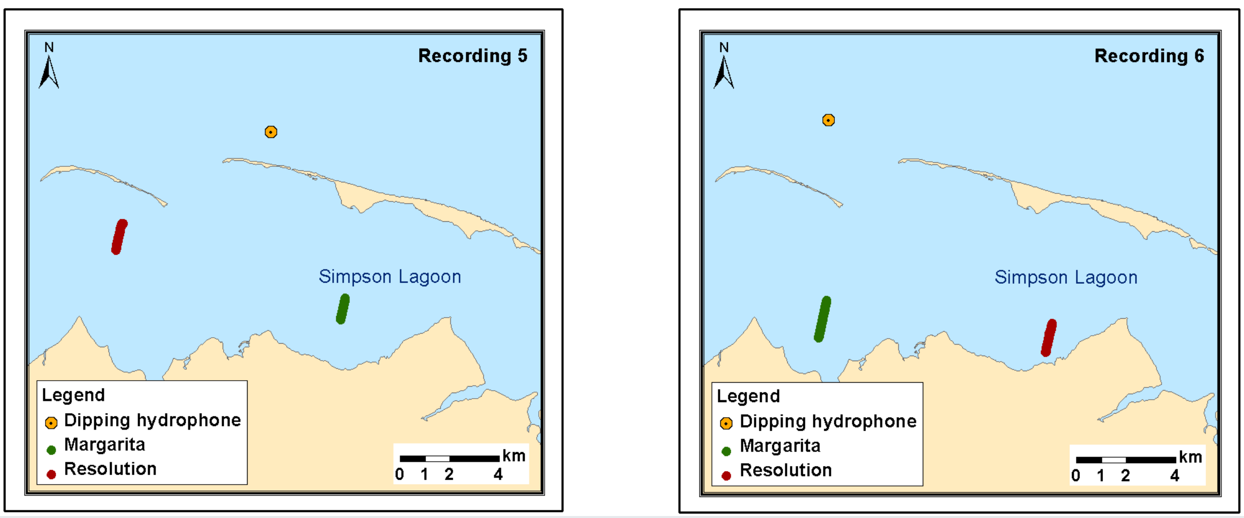
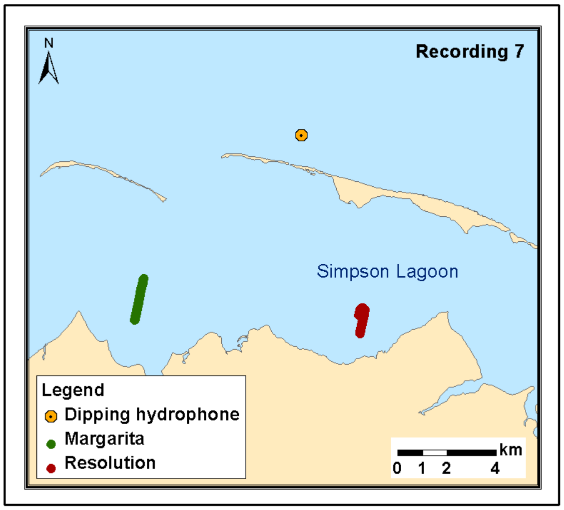


Figure 59. Locations of the *Margarita* and *Resolution* when the 320 in^3 arrays were operating during (left) Recording 5 and (right) Recording 6.



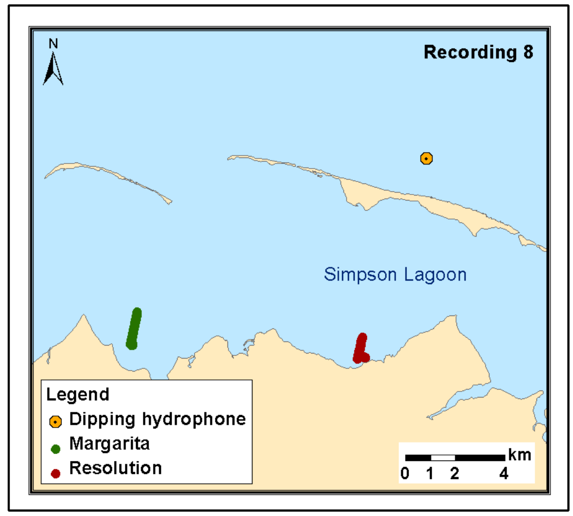


Figure 60. Locations of the *Margarita* and *Resolution* when the 320 in^3 arrays were operating during (left) Recording 7 and (right) Recording 8.

3.4. Long-Term Measurements

The results of the analysis of the AMAR data to determine the degree to which the barrier islands block seismic survey sound propagation are presented in Section 3.4.1. The automated ambient data analysis results for percentiles (Section 3.4.2), spectrograms, and 1/3-octave band level plots (Section 3.4.3) are also presented.

3.4.1. Propagation Effects

Seismic pulse levels from each of the three AMARs were computed for two periods when a single seismic vessel was operating near AMAR 2 to see how sound propagates through gaps in the barrier islands and how it is attenuated through the barrier islands. Sound levels from the *Margarita's* 320 in^3 array were computed during the period 17:14–17:40 on 4 August 2012; for the *Resolution's* 320 in^3 array, the period was 13:52–13:55 on 7 August 2012. Figure 61 shows the location of the *Margarita* and *Resolution* relative to the AMARs and barrier islands during the analyzed periods.

Figure 62 shows sound levels versus range for pulses from the 320 in^3 airgun arrays on the *Margarita* and *Resolution*. Pulses measured on AMAR 1 were low-pass filtered at 150 Hz. Pulses measured on AMAR 3 were low-pass filtered at 50 Hz. Figures 63 and 64 show pulse waveforms and spectra from the *Resolution's* 320 in^3 airgun array that were recorded on AMARs inside and outside the barrier islands.

The regression lines drawn through these plots of level versus range, and their associated equations, should not be taken as valid estimators of source level. In all cases the propagation regime over longer distances is influenced by the effect of the extremely shallow bottom (even in the case of the propagation through the gap in the islands) that create a transmission loss quite unrepresentative of the regime at close ranges from the source. It is not possible, therefore, to extrapolate the trend to the notional 1m distance at which source levels are expressed.

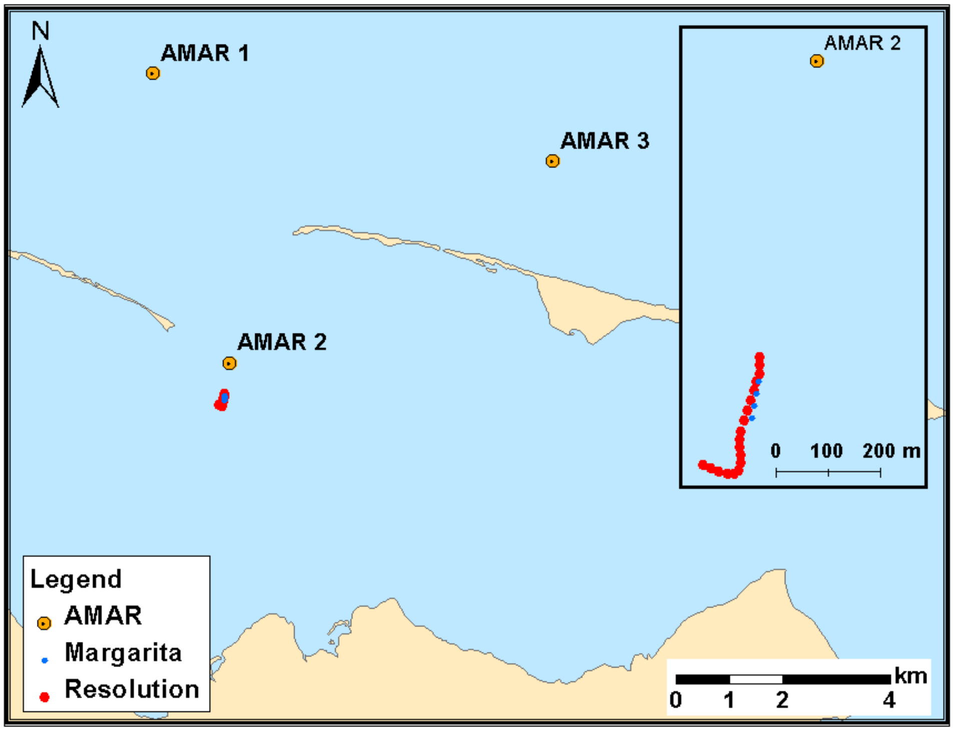


Figure 61. Track of the *Margarita* during 17:14-17:40 4 Aug 2012 AKDT and the *Resolution* during 13:52-13:55 7 Aug 2012 AKDT. For each period, the seismic vessel was operating its respective 320 in^3 airgun arrays.

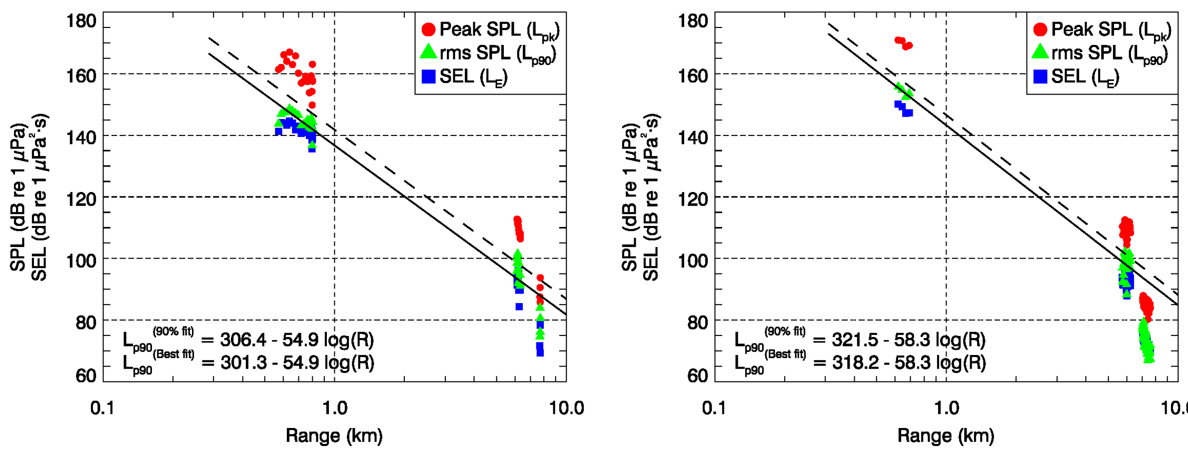


Figure 62. Peak SPL, rms SPL, and sound exposure level (SEL) versus range for the *Resolution's* 320 in^3 airgun array (left) and the *Margarita's* 320 in^3 airgun array (right) operating inside the barrier islands (Figure 61).Pulses at ranges less than 1 km were recorded inside the barrier islands on AMAR 2. Pulses at 6 km were recorded outside the barrier islands on AMAR 1 after propagating between two barrier islands. Pulses at 7-8 km were recorded outside the barrier islands on AMAR 3 after propagating through a barrier island. Best fit and 90% fit lines were made to pulse levels on AMARs 1 and 2.

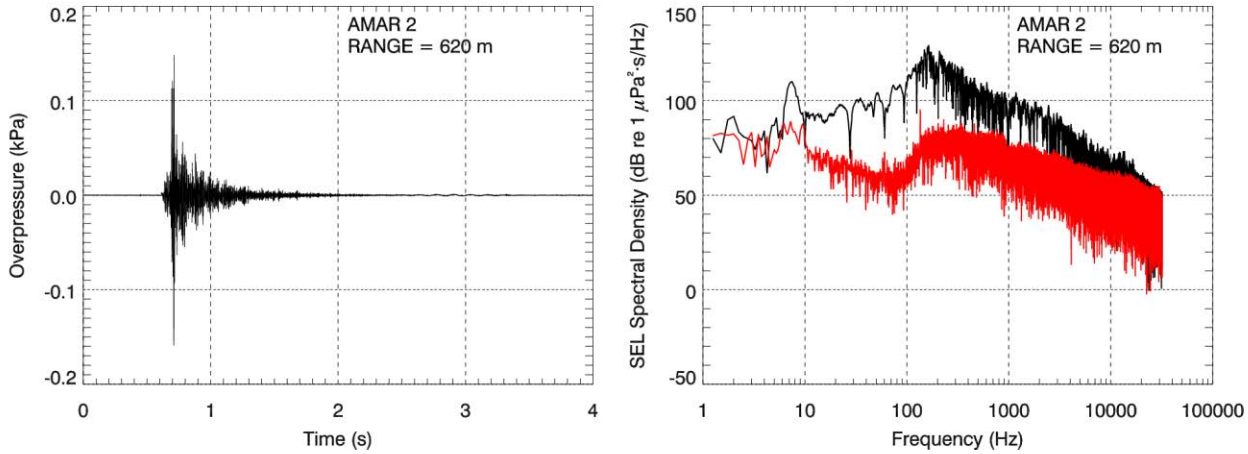


Figure 63. Waveform (left) and SEL spectral density (right) of a pulse from the *Resolution*'s 320 in^3 airgun array measured on AMAR 2 at 620 m range. The red line on the spectral density plot shows the background noise from a time window preceding the pulse.

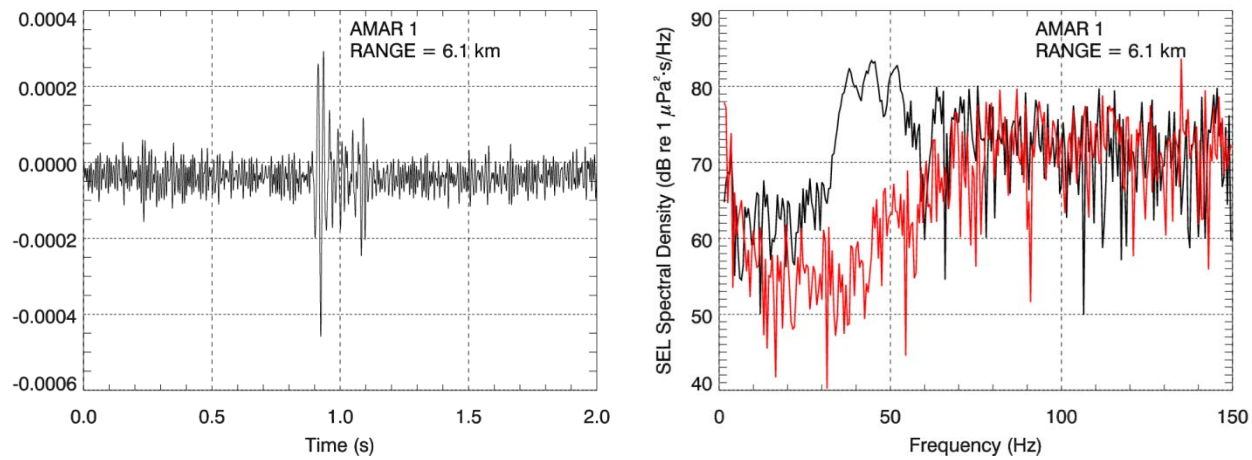


Figure 64. Waveform (left) and SEL spectral density (right) of a pulse from the *Resolution's* 320 in^3 airgun array measured on AMAR 1 at 6.1 km range. A low-pass filter with a cutoff frequency of 150 Hz was applied to the waveform to remove high frequency ambient noise. The red line on the spectral density plot shows the background noise from a time window preceding the pulse.

3.4.2. Percentiles

The frequency domain ambient analysis of the data recorded on each AMAR for the entire deployment determined 1 Hz resolution spectral density values for each minute recorded. Figures 65–67 show these percentiles for each AMAR.

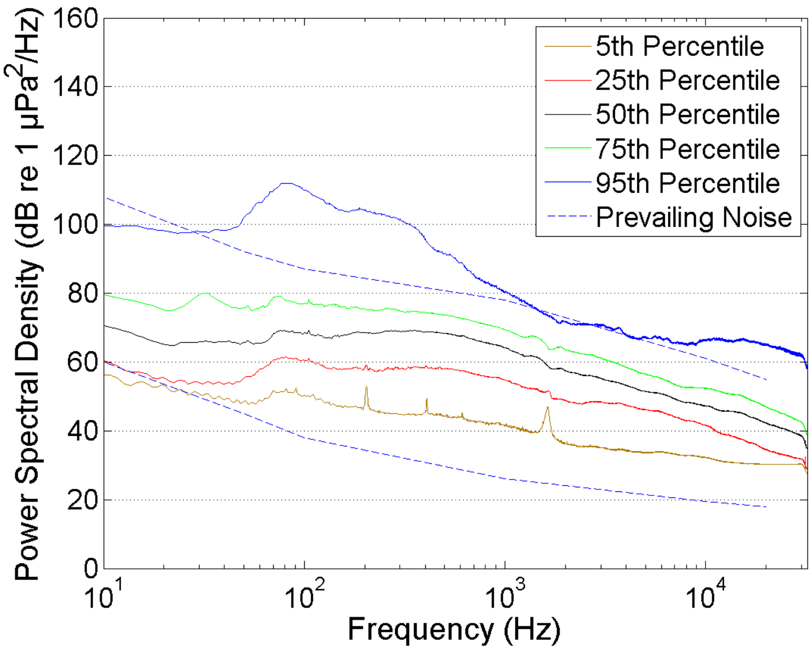


Figure 65. Ambient noise percentiles for AMAR 1 outside barrier islands, 27 Jul to 9 Sep 2012. The dashed lines are the "Limits of Prevailing Noise" from the Wenz curves, Figure 9.

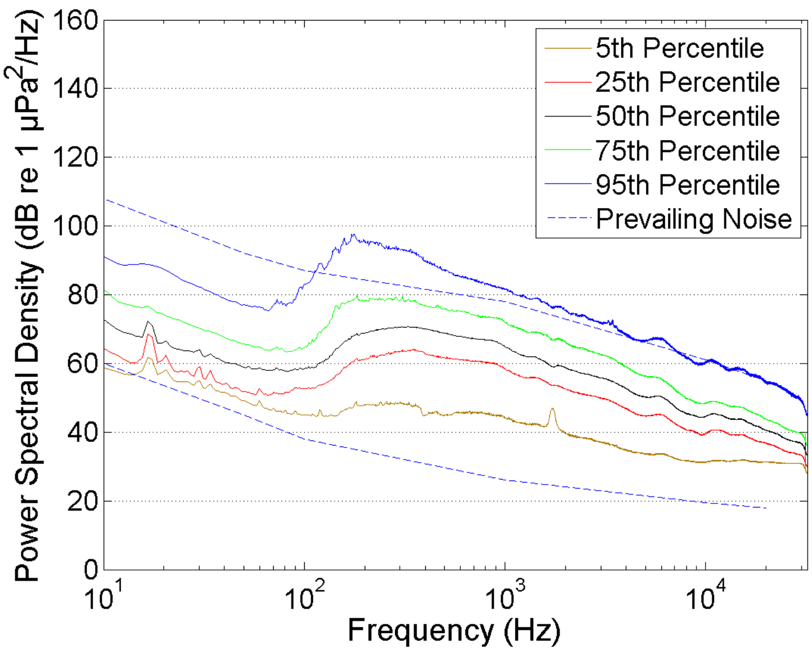


Figure 66. Ambient noise percentiles for AMAR 2 inside barrier islands, 27 Jul to 7 Sep 2012. The dashed lines are the "Limits of Prevailing Noise" from the Wenz curves, Figure 9.

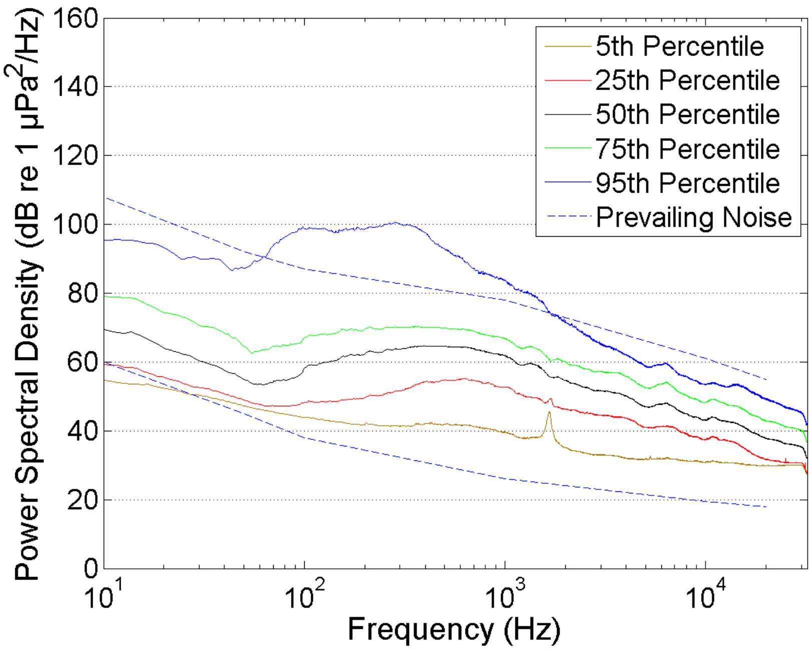


Figure 67. Ambient noise percentiles for AMAR 3 outside barrier islands, 27 Jul to 9 Sep 2012. The dashed lines are the "Limits of Prevailing Noise" from the Wenz curves, Figure 9.

3.4.3. Spectrograms and 1/3–Octave Band Levels

The frequency domain ambient analysis of the data recorded on each AMAR for the entire deployment also generated spectrograms (Figures 68, 70, and 72) and 1/3-octave band level plots (Figures 69, 71, and 73). The 1/3-octave band level plots consist of box/whisker plots that show the 25th and 75th percentiles through the position of the top and bottom of the box, and the 50th percentile through the band inside the box. The ends of the whiskers represent the maximum and minimum levels in that band. The brown line represents the mean value, which is strongly influenced by high intensity outliers, such as seismic.

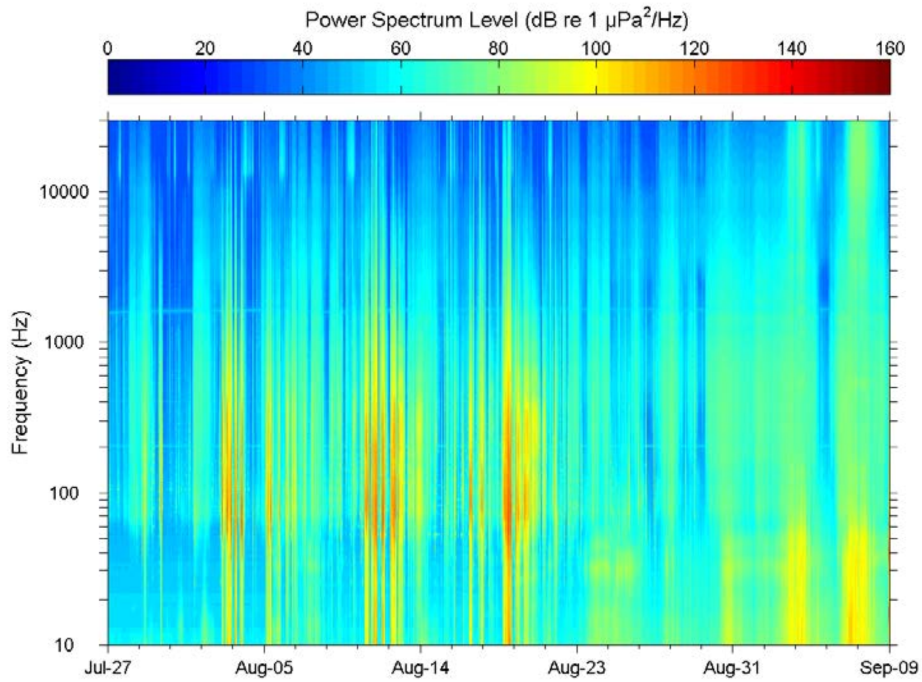


Figure 68. Spectrogram of underwater sound at AMAR 1, outside barrier islands, 27 Jul 2012 to 9 Sep 2012. 1 Hz resolution, Hamming window, 50% window overlap.

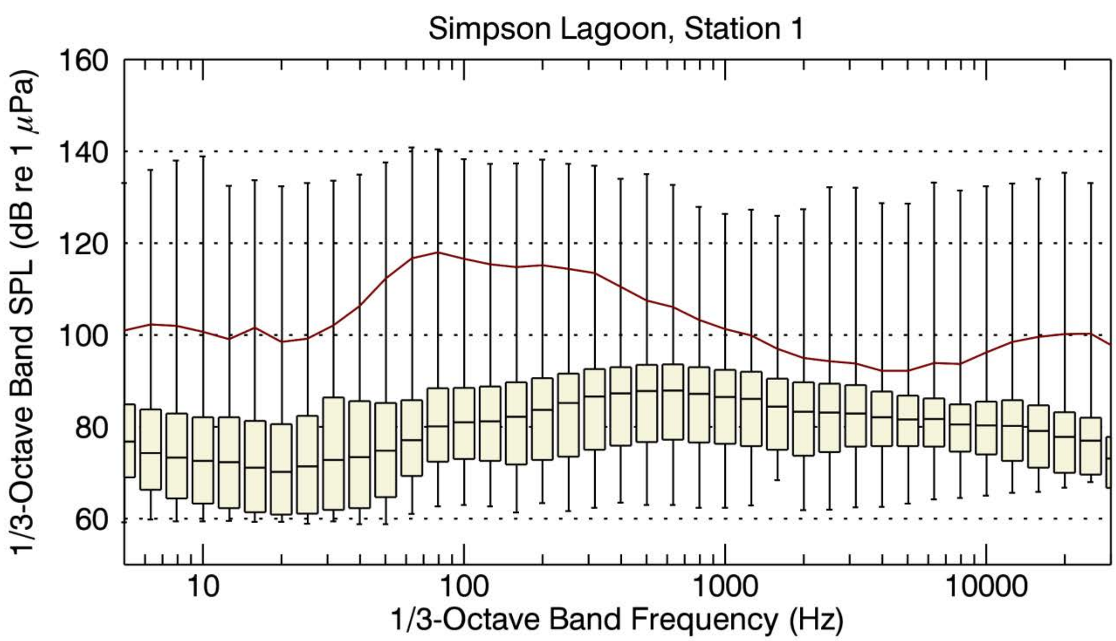


Figure 69. 1/3-octave band SPL box/whisker plot for AMAR 1, outside barrier islands, 27 Jul 2012 to 9 Sep 2012. The plots show the 50th percentile (the line in the middle of each box), 25th and 75th percentiles (top and bottom of each box), and the minimum and maximum (top and bottom of whiskers), while the curve above the boxes shows the mean value, which is strongly influenced by high intensity outliers, including seismic pulses

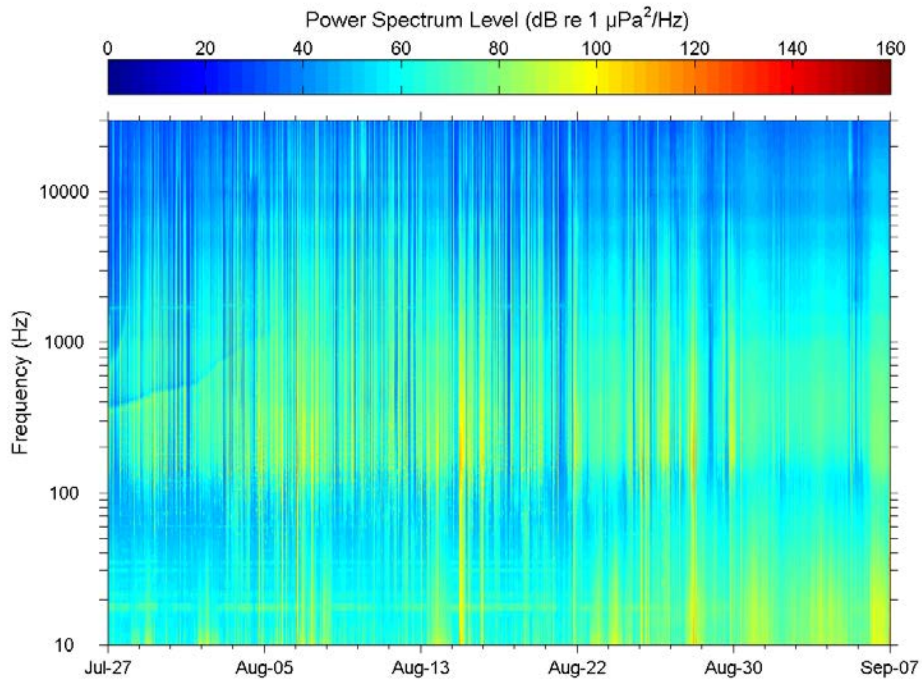


Figure 70. Spectrogram of underwater sound at AMAR 2, inside barrier islands, 27 Jul to 7 Sep 2012. 1 Hz resolution, Hamming window, 50% window overlap.

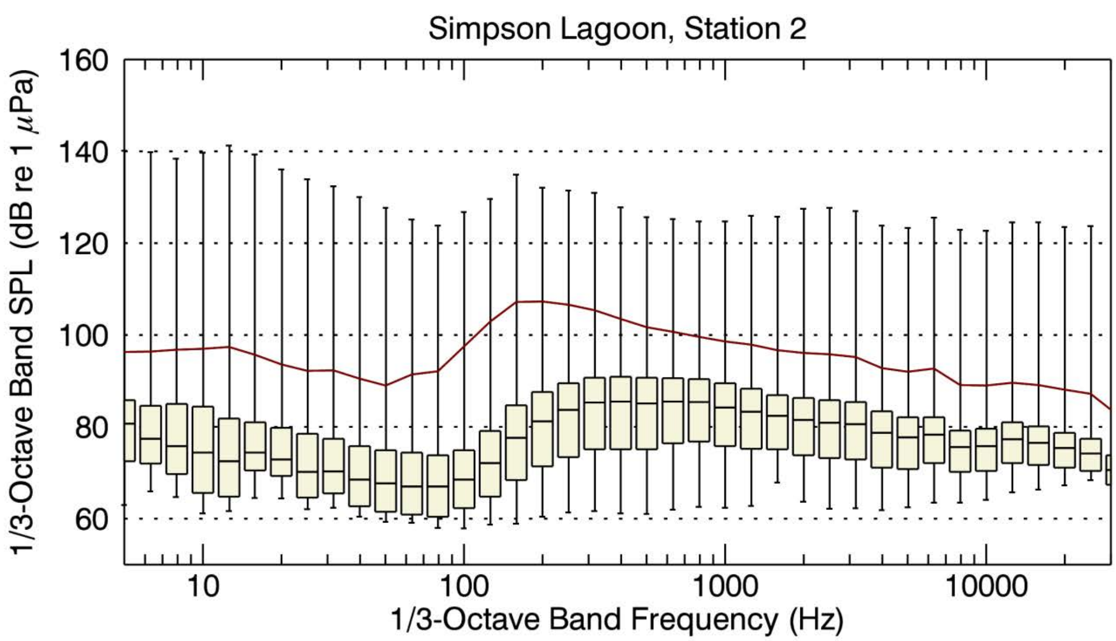


Figure 71. 1/3-octave band SPL box/whisker plot for AMAR 2, inside barrier islands, 27 Jul to 7 Sep 2012. The plots show the 50th percentile (the line in the middle of each box), 25th and 75th percentiles (top and bottom of each box), and the minimum and maximum (top and bottom of whiskers), while the curve above the boxes shows the mean value, which is strongly influenced by high intensity outliers, including seismic pulses

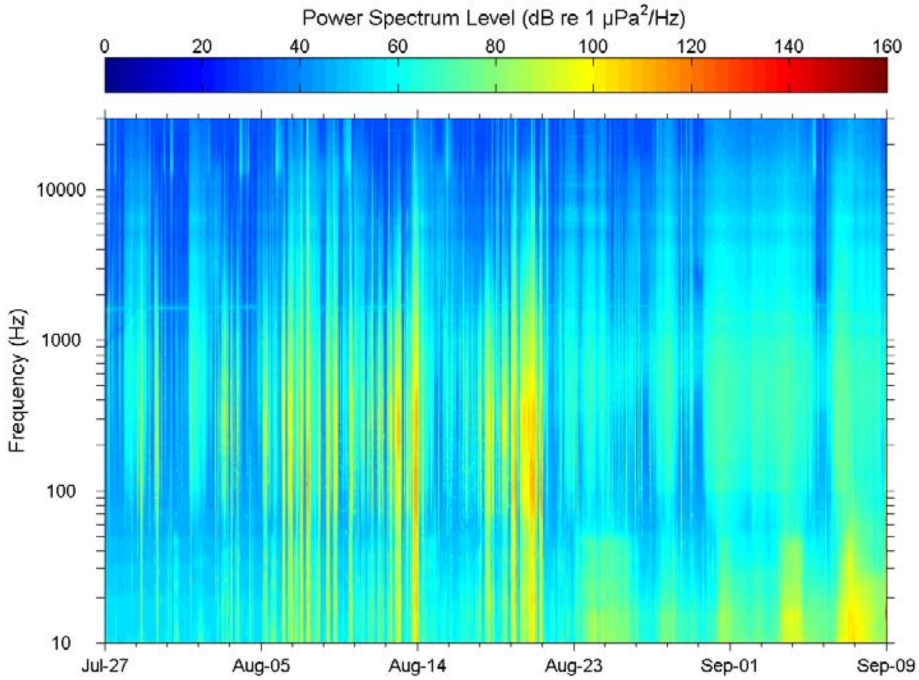


Figure 72. Spectrogram of underwater sound at AMAR 3, outside barrier islands, 27 Jul to 9 Sep 2012. 1 Hz resolution, Hamming window, 50% window overlap.

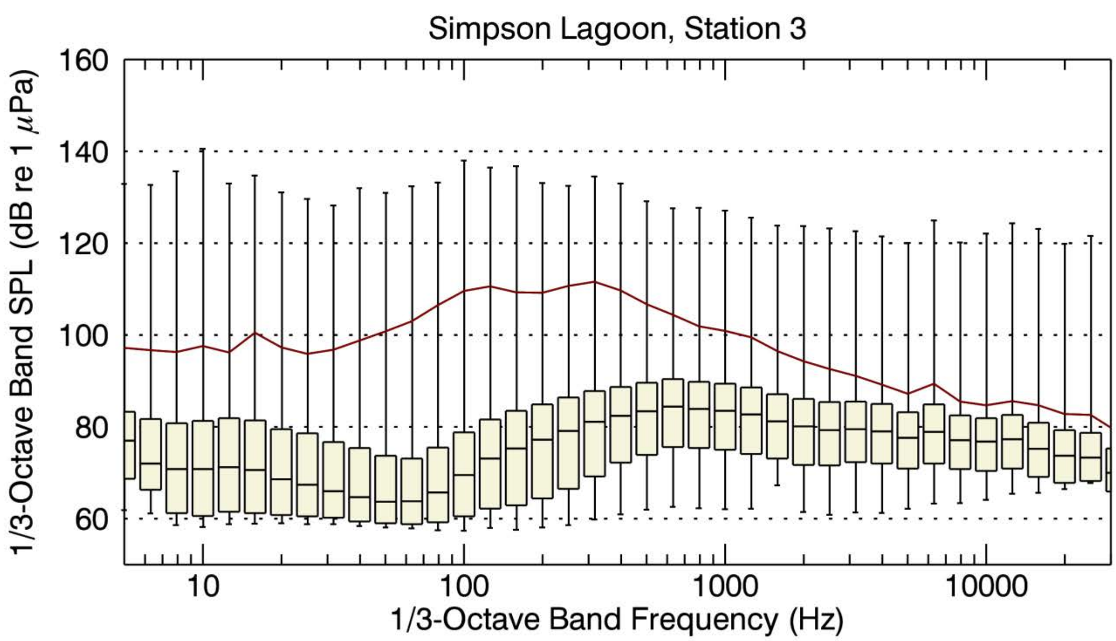


Figure 73. 1/3-octave band SPL box/whisker plot for AMAR 3,outside barrier islands, 27 Jul to 9 Sep 2012. The plots show the 50th percentile (the line in the middle of each box), 25th and 75th percentiles (top and bottom of each box), and the minimum and maximum (top and bottom of whiskers), while the curve above the boxes shows the mean value, which is strongly influenced by high intensity outliers, including seismic pulses

4. Discussion

4.1. SSV/SSC Outside Barrier Islands

4.1.1. SSV

The 640 in^3 airgun array and 40 in^3 mitigation airgun outside the barrier islands were both modeled pre-season, which allowed us to compare their measured results to model-based estimates. The 320 in^3 airgun array outside the barrier islands was not modeled pre-season; the measured results, therefore, cannot be compared to model-based estimates.

The sound speed profile (SSP) measured outside the barrier islands on three different days was consistently downward refracting (Section 3.1), which means the sound energy was directed into the absorptive substrate across the area. These profiles were measured in shallow water (less than 15 m) across the survey region outside the barrier islands; the water column in such conditions can be unstable as weather events (storms/currents) can rapidly redistribute its layers.

The SSP strongly affects the propagation of sounds in shallow water. The downward-refracting profile caused the sound energy to be directed to the ocean floor, which caused higher levels at close range, but increased the attenuation at longer distances.

The pre-season modeling used a weakly refracting SSP (almost uniform), which, along with other propagation parameters, was drawn from a nearby region for a different survey. The difference between the modeled and measured sound speed profiles was the dominant influential factor in the difference between the measured and modeled levels outside the barrier islands, and indicated a strong site sensitivity of the propagation.

The SSP caused the low frequency pulse component to propagate extremely well at close range, which is a significant contributor to the higher than expected received levels within 1000 m of the source.

For the 640 in^3 airgun array, the pre-season modeled radii, which represent broadside levels, underestimated the measured distances for the 190 and 180 dB thresholds, but overestimated the 160 and 120 dB radii (Table 17). Similarly, for the 40 in^3 mitigation airgun, the pre-season modeled radii underestimated the measured distances for the 180 and 160 dB thresholds (close range), but overestimated the 120 dB threshold distance (Table 17). Note that for these latter measurements, the pre-season 190 dB had only been given as an upper limit.

The underestimation of close range levels required an increase of the close range initial mitigation radii used by the Marine Mammal Observers (MMOs), but a reduction of the distant radii.

Another difference between the measured and modeled results was the sound exposure level (SEL) to rms SPL conversion offset the model used. For sound propagation outside the barrier islands, the model used a constant +9 dB conversion factor, which measurements have shown was too simplistic (Figure 14). To exemplify this, a conversion of +12 to 15 dB is required close to the source (180 and 190 dB thresholds) in the endfire direction for the 640 in^3 airgun array, , but beyond the 160 dB threshold point, a conversion offset is not required. In the broadside direction, a similar conversion is required at close ranges, but only a slight conversion offset (+2 dB) at the 160 dB threshold point, which is still much smaller than the estimated conversion.

Further examination of the effect of the SSP on the SEL showed that it caused the measured sound exposure level (SEL) to differ from the modeled SEL through discrepancies in the estimated pulse length. Longer pulse lengths give smaller differences between rms SPL and SEL. This, coupled with the differences between the modeled and observed SEL to rms SPL conversion offset, resulted in the observed levels being higher than expected at closer ranges to the source (180 and 190 dB thresholds), but lower than predicted farther from the source (beyond the 160 dB threshold) (Table 17).

Sound from the 320 in^3 airgun array propagated similarly to the 640 in^3 airgun array operating in the same environment, with good substrate and water propagation within 1000 m of the source, and predominantly substrate propagation beyond 5000 meters. Therefore, we believe that had the 320 in^3 airgun array been included in pre-season modeling, similar differences would have been observed in the measurements.

Table 17. Outside barrier islands: Comparing measurements with pre-season estimated marine mammal safety radii. Distances are maximized over direction and are based on the 90th percentile fits.

	Safety radii in meters			
Airgun Type	*Threshold (dB re 1 µPa)*	*Pre-Season Estimated*	*90th Percentile Measured*	*Ratio (%)*
640 in^3 airgun array	190	120	516	430
	180	950	1386	146
	160	5 500	4616	84
	120	44 000*	14 163	32
320 in^3 airgun array	190		360	
	180		1134	
	160		4265	
	120		13 313	
40 in^3 mitigation array	190	< 50	24	48
	180	< 50	158†	316
	160	810	1602	198
	120	16 000	9 221	57

*Computed based on 2 dB SPL-SEL conversion factor. See Section 3.1.2 for more detail.
†Actual maximum range from measurements.

4.1.2. SSC

The *Resolution* and *Margarita* transited the same track line outside the barrier islands ranges, an area in which the water ranged in depth between approximately 12.8 m and 13.4 m. The *Resolution* transited at close to the expected operating speed of 5.5 kts, Figures 29 and 30. The *Margarita* moved faster than the typical survey operating speed, at 7.7 kts, Figures 33 and 34. The SPL fits of both vessels were calculated in two sections because the difference in levels between the peak period and the remainder of the track due to differing transit times and periods of peak levels. For the *Resolution*, the spectrograms (Figure 31) and the power spectrum density (PSD) plots (Figure 32) show the nature of the vessel noise has defined tonal components, with the primary two centered at 70 Hz and 125 Hz, and are the only components distinguishable at

664 m. The Lloyd mirror pattern is weak, and present only in the recording from OBH A2 (above 100 Hz), but are not present at OBH B2. The spectrograms show the *Margarita* has a different signature (Figure 35) and power spectrum density (PSD) (Figure 36). The *Margarita* has defined tonal components centered at 70 Hz and 200 Hz, and Lloyd mirror pattern above 100 Hz, which are still distinguishable at OBH B2, 660 m distant.

Because the *Resolution* is a jetboat and the *Margarita* is propeller driven, they have different signatures, with the *Resolution* being significantly quieter (Table 18).

Table 18. Threshold radii for the vessels at the SSC site outside the barrier islands, as determined from function fit to SPL versus distance data in Figures 30 and 34.

	Resolution (5.5 kts)		Margarita (7.7kts)	
Threshold (dB re 1 µPa)	*Best-Fit Line Radius (m)*	*90th Percentile Radius (m)*	*Best-Fit Line Radius (m)*	*90th Percentile Radius (m)*
160	<1*	1*	6†	8†
150	1*	2*	17	24
140	5*	7*	53	73
130	17	28	162	222
120	47	61	889	1151

*Extrapolated from minimum measurement range of 14.3 m.
†Extrapolated from minimum measurement range of 15.5 m.
These distances are well inside the near-field of such a distributed source, and should be considered only as notional values.

4.2. SSV/SSC Inside Barrier Islands

4.2.1. SSV

The 320 in^3 airgun array and 40 in^3 mitigation airgun inside the barrier islands were both modeled pre-season, which allowed us to compare their measured results with model-based estimates.

The sound speed profile (SSP) was measured inside the barrier islands on only one occasion and was found to be downward refracting, similar to outside the barrier islands. This means that sound energy was directed into the absorptive substrate across the area. The instability of the SSP inside the barrier islands in the extremely shallow water can be very high. The limited depths also restricted the sounds to a narrow region, leading to many attenuating boundary interactions.

Inside the barrier islands both the depth and the SSP influenced the propagation of sounds in shallow water. The downward-refracting profile caused the sound energy to be directed to the ocean floor, resulting in higher levels at close range, but increasing the attenuation at longer distances.

The pre-season modeling used a weakly refracting SSP (almost uniform), which, along with other propagation parameters, was drawn from a nearby region for a different survey. The modeling depths were also slightly greater than the actual depths encountered inside the islands due to changing bathymetry. The different SSP and very shallow depth are the dominant factors that influenced the difference in the measured and modeled levels.

The recorders were intentionally placed, based on the available cartography, along the axis of a slight depression in the otherwise almost flat seafloor, oriented in the direction of the gap between the barrier islands. This placed them along a somewhat deeper channel (about 30 cm) compared to the track line along which the SSV would be run. Because the water was very shallow (1.8 m), this represented an appreciable difference, likely enhancing sound propagation in the broadside direction compared to the endfire.

For the 320 in^3 airgun array, the pre-season modeled radii underestimated the measured distance for the 190 dB threshold, but were comparable to the 180 to 160 dB thresholds. For the 120 dB threshold, the comparison is mixed because of issues with extrapolating a broadside estimate from the measurements as described in a Section 3.2.2. Table 19 shows the measured endfire radius and the extrapolated broadside radii, the latter only for completeness rather than as a realistic estimate.

The 40 in^3 mitigation airgun differed slightly from the 320 in^3 airgun array, as the pre-season modeled radii underestimated the measured distances for the 180 and 160 dB thresholds (the pre-season 190 dB had only been given as an upper limit), but overestimated the 120 dB threshold (Table 19). Another difference between the measured and modeled results was the SEL to rms SPL conversion offset the model used. Inside the barrier islands, the conversion factor for the array is range-dependent, between +15 and +3 dB. Upon examining the 320 in^3 airgun array measurements, this relationship is overly complex (Figure 39). In the endfire direction, the conversion is +20 dB within 500 m, but this quickly goes to zero as the SEL and rms SPL results align. In the broadside direction, the offset is a constant +20 dB within 1 km however after this distance the SEL and rms SPL results come close to aligning.

The effect of the SSP on the SEL inside the barrier islands was the same as outside the islands, with discrepancies in the estimated pulse length. This, coupled with the differences between the modeled and observed SEL to rms SPL conversion offset, resulted in the observed levels being higher than expected at closer ranges to the source (190 dB threshold) but lower than predicted at greater distances from the source (near the 120 dB threshold).

The difference between the original modeled estimate of 5700 m for the 320 in^3 airgun array 120 dB mitigation radius, and the measured value of 2528 m in the endfire direction, is significant in terms of long-range mitigation both inside and outside the barrier islands. Despite the significant difference in ranges, to be conservative, we adopted the modeled estimate of 5700 m. This was validated when we analyzed the AMAR long-term measurements (Section 3.4), which showed that at approximately 6 km in range the received levels outside the barrier islands from the 320 in^3 airgun array operating inside the barrier islands were a maximum of 100 dB (90% rms SPL) (Figure 62). Therefore, the 120 dB threshold would have been well within the selected threshold, and the AMAR measurements show that with the barrier islands between the source and receiver, the threshold distance would have been approximately only 2000 m.

Table 19. Inside barrier islands: Measurement comparison with pre-season estimated marine mammal safety radii. Distances are maximized over direction and are based on the 90th percentile fit lines.

	Safety radii in meters			
Airgun Type	*Threshold (dB re 1 µPa)*	*Pre-Season Estimated*	*90th Percentile Measured*	*Ratio (%)*
320 in³ airgun array	190	160	260	163
	180	480	472	98
	160	1 500	1545	103
	120	5 700	2528*	44
			16 598†	291
40 in³ mitigation array	190	16	138	863
	180	59	293	497
	160	700	933	133
	120	3 700	3242	87

* Measured endfire.
† Extrapolated broadside.

4.2.2. SSC

The *Storm Warning* transited the track line in water 2 m deep at an average speed of 6.3 kts, which was faster than the specified operating speed of the vessel during the survey. The peak levels recorded from the vessel occurred over a brief period, approximately 25 seconds, and 200 m (Figures 74, 53, and 54). The difference in received levels required the SPL fit be calculated in two sections. The effect of the vessel's jet complicated analysis, with all departure results within 60 m, after an invalid 3 m closest point of approach (CPA), which was due the direct flow from the jet nozzle causing spurious pressure effects (non-acoustic noise spike) on the recorder.

The spectrograms (Figures 75 and 55) and the power spectrum density (PSD) plots (Figure 56) showed the nature of the vessel noise lacks defined tonal components, but instead had a band-limited broadband noise structure from 100 to 3000 Hz with Lloyd mirror pattern. The structure of the vessel noise reflects the jetboat's properties: it doesn't have a true propeller but does have a flat-bottomed hull. These features make the vessel relatively quiet; it has no true vessel sound components under 100 Hz, but has a 90th percentile radius of 134 m at a threshold of 120 dB.

The noise characteristics of this jet propelled boat in extremely shallow water are complex, with the vessel hull effectively shielding sound from reaching the recorder at extremely close approach, and the direct flow from the jet nozzle causing spurious pressure effects (non-acoustic noise spike) on the recorder on the departure track (Figure 53). These anomalies are discussed in this section, but were excluded from the analysis because we appropriately selected unaffected data segments.

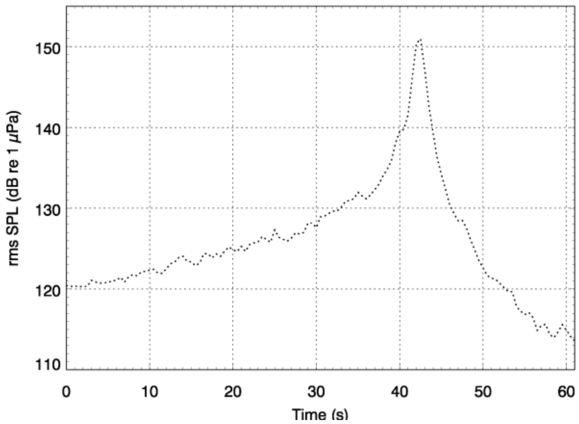


Figure 74. *Storm Warning* rms SPL versus time, in 1 s intervals as it transited past OBH A1 at 6.3 kts with a 3 m CPA, from 100 m before to 97 m after.

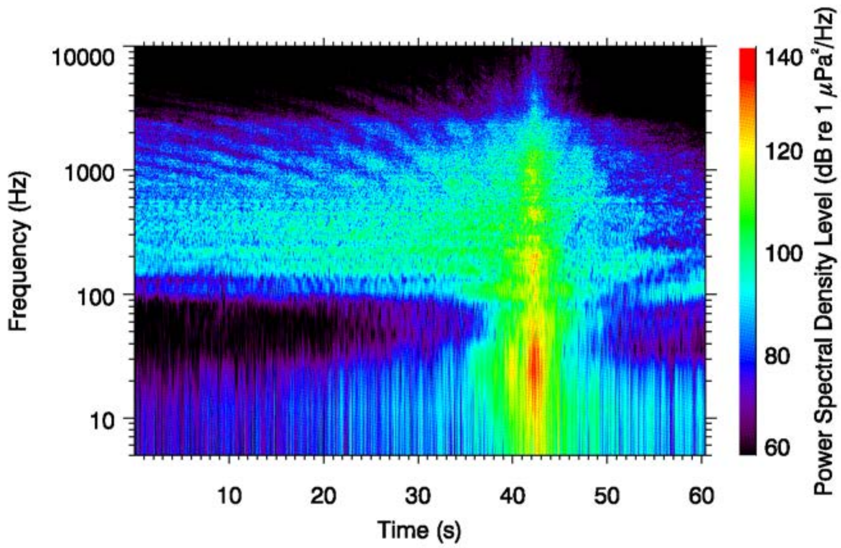


Figure 75. Spectrogram of the *Storm Warning* transiting at 6.3 kts, CPA of 3 m, from 100 m before to 97 m after; 8192 pt FFT, 96 kHz sample rate, Hanning window, 87.5% overlap.

4.3. Long-Range Measurements

The dipping hydrophone recordings did not detect seismic pulses from the active 320 in^3 arrays. To verify the sound levels on the dipping hydrophone, for two of the recordings we analyzed matching periods from the long-term AMAR data. Figure 76 shows the locations of all sampling sites for both types of recorders. Maps of the recording geometry and spectrograms from the dipping hydrophones and AMARs for the two instances considered are shown in Figures Figure 77–82. For Recording 2, pulses were detected inside the barrier islands on AMAR 2 but not outside the barrier islands on AMAR 3. For Recording 4, the *Kimberlin Kat*'s engines were not turned off so the dipping hydrophone detected only vessel noise; over the same period seismic pulses were detected inside the barrier islands on AMAR 2 but not outside the barrier islands on AMAR 1. These results are consistent with the shallow water environment inside the barrier islands severely attenuating pulses as they propagated through the sub-bottom and outside the barrier islands. This effect is discussed in more detail in Section 4.4.1.

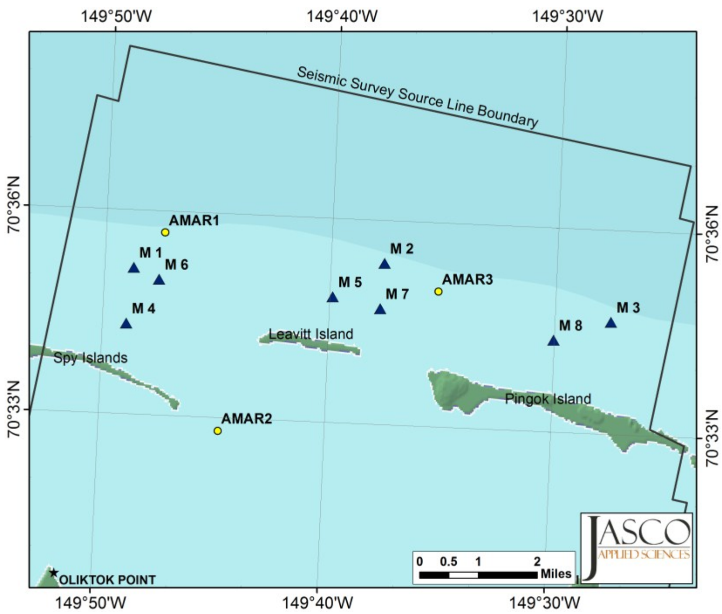


Figure 76. Locations where AMARs recorded and dipping hydrophone measurements were taken.

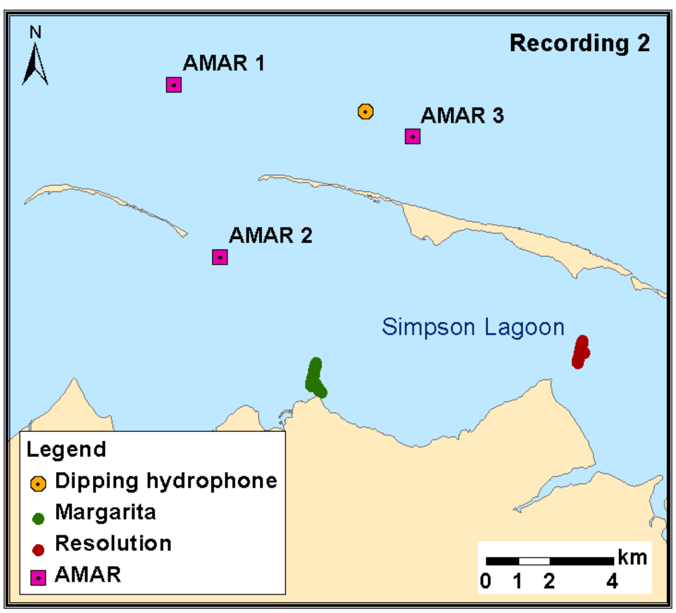


Figure 77. Locations of the *Margarita* and the *Resolution* during Recording 2 at 13:03 AKDT on 29 Aug 2012.

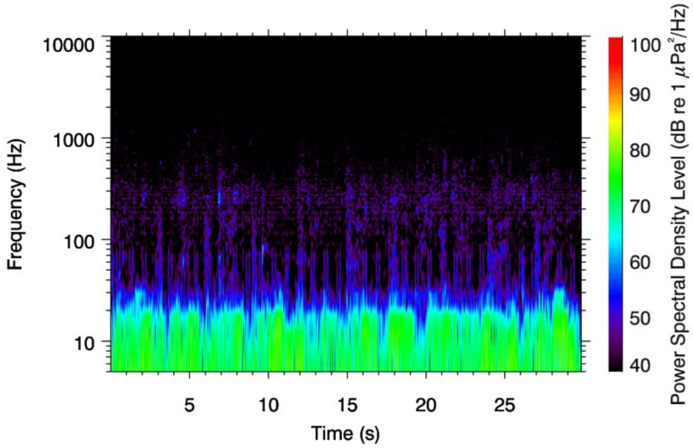


Figure 78. Spectrogram from the dipping hydrophone (Recording 2) starting at 13:03 AKDT on 29 Aug 2012; FFT length 16 384 pts; Hanning window, 87.5% overlap.

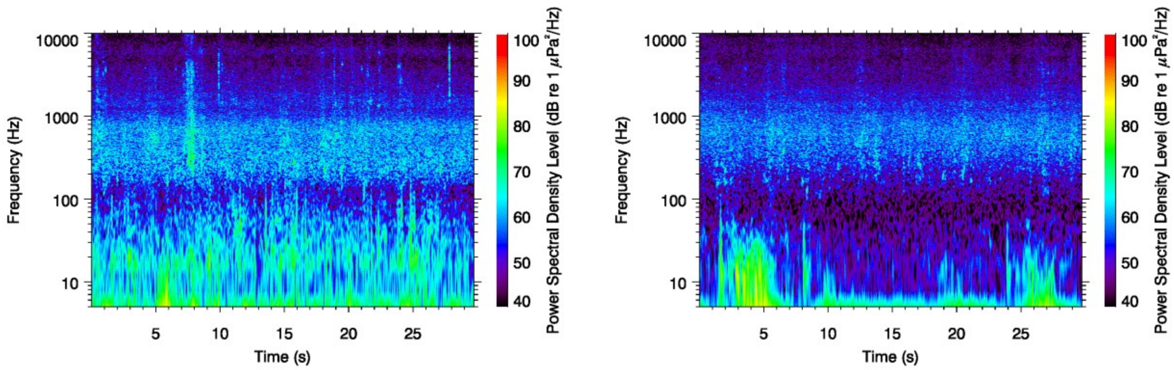


Figure 79. Left: Spectrogram from AMAR 2 starting at 13:03 AKDT on 29 Aug 2012; FFT length 16 384 pts; Hanning window, 87.5% overlap. Airgun pulses from the *Margarita*'s 320 in^3 airgun array are visible above 1000 Hz at 1, 10, 19, and 28 seconds into the spectrogram. Wave noise is visible at 7-8 seconds between 200 and 4000 Hz. Right: Spectrogram from AMAR 3 starting at 13:03 on 29 Aug 2012 AKDT. FFT length 16384 pts. Hanning window, 87.5% overlap. No airgun pulses were detected during this time.

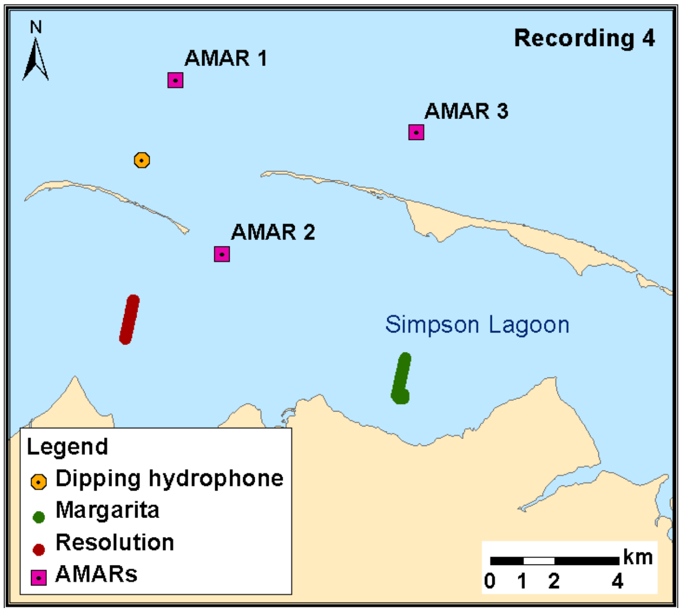


Figure 80. Locations of the *Margarita* and the *Resolution* during Recording 4 at 12:41 AKDT on 1 Sept 2012.

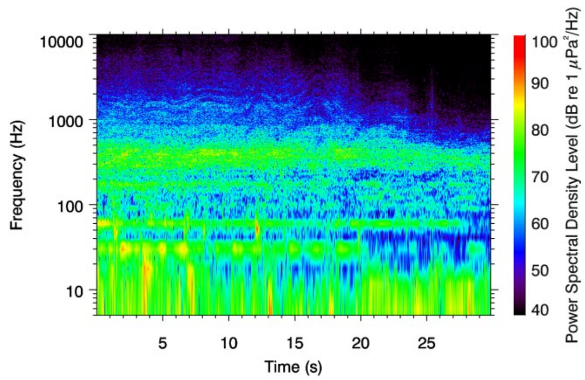


Figure 81. Spectrogram from dipping hydrophone Recording 4 starting at 12:41 AKDT on 1 Sept 2012; FFT length 16 384 pts, Hanning window, 87.5% overlap.

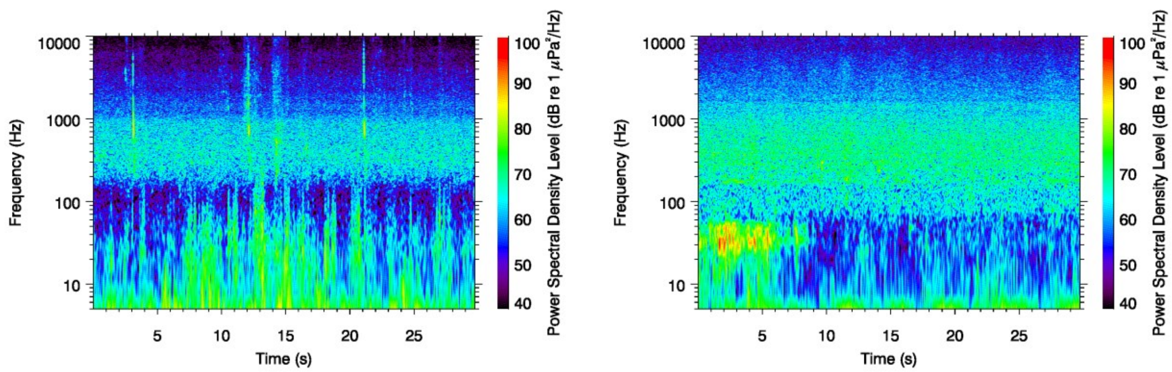


Figure 82. Left: Spectrogram from AMAR 2 starting at 12:41 on 1 Sep 2012 AKDT: FFT length 16384 pts, Hanning window, 87.5% overlap. Airgun pulses from the *Resolution's* 320 in^3 airgun array are visible at 3, 12, and 21 seconds into the spectrogram. The pulse energy is above 100 Hz. A pulse-like sound from an unknown source was observed at 14-15 seconds into the spectrogram. Right: Spectrogram from AMAR 1 starting at 12:41 on 1 Sep 2012 AKDT: FFT length 16 384 pts, Hanning window, 87.5% overlap. No airgun pulses were detected during this time. The signal between 20 and 50 Hz and 1 and 9 seconds is too long to have been generated by the seismic sources used in this survey.

4.4. Long-Term Measurements

4.4.1. Propagation Effects

Sound levels for pulses propagating from inside to outside the barrier islands were computed to determine the transmission loss between the two regions and the degree to which the barrier islands block sound transmission (see Section 3.4.1). Several pulses were analyzed from the *Margarita's* and *Resolution's* 320 in^3 arrays when they operated inside the barrier island. Pulses received inside the barrier islands were recorded on AMAR 2. Pulses that propagated offshore through a navigable channel between the barrier islands were recorded on AMAR 1. Pulses that propagated offshore through one of the islands were recorded on AMAR 3. The differences in spectral density show the effect of the barrier islands on sound propagation.

Pulse spectral density inside the barrier islands exceeded background levels at frequencies above 10 Hz and peaked between 100 and 200 Hz. Most of the pulse energy propagated through the water directly to the recorder.

Pulse spectral density for the same pulses after they propagated between and outside the barrier islands exceeded background levels at frequencies between 10 and 80 Hz. Even though the path from the array to the recorder was not blocked by an island, the shallow water inside the barrier islands prevented long-range sound propagation at frequencies over 80 Hz. The detected low frequency energy propagated through the sub-bottom and radiated energy back into the water column.

Pulse spectral density for the same pulses after they propagated through a barrier island exceeded background levels at frequencies between 10 and 30 Hz. The path from the array to the recorder was blocked by an island and the pulse propagated through the sub-bottom, reradiating energy back into the water column. Transmission loss was larger for this path compared to the unobstructed path to AMAR 1 indicating that sound was attenuated significantly as it travelled through the sub-bottom.

4.4.2. Percentiles, Spectrograms, and Band Levels

Power spectral density levels (see Section 3.4.2) are highest in the frequency range 60–1 000 Hz, which is consistent with the Wenz curves (Figure 9) for sea-state and vessel noise in shallow water. The raised portion of the 95th percentile above the upper Wenz curve for each AMAR is due to the contribution of the seismic survey. This level is higher for the outside barrier islands AMARs (Figures 65 and 67), most likely due to the use of the 640 in^3 airgun arrays in this area and the better propagation conditions. The inside barrier island AMAR, AMAR 2 (Figure 66), recorded a lower 95th percentile level, most likely due to the comparatively poor propagation conditions and the maximum array size of 320 in^3.

As the AMARs outside the barrier islands received low level pulses when the survey was conducted inside the islands, their 75th percentiles are lower when compared to AMAR 2, which was inside the barrier islands. This means that the outside AMARs received pulses from a source inside the islands 75% of the time, which reflects the amount of time the survey was operational inside the islands, compared to the length of the deployment.

The spectrograms for the outer long-term AMARs 1 and 3 (see Section 3.4.3) show that seismic survey activity outside the barrier islands only occurred in the first part of the survey, prior to 22 August. After that time no further seismic acquisition was permitted outside the islands, and the recorded sounds detectable in the spectrograms were mainly attributable to vessel noise and weather events. Levels inside the barrier islands recorded at AMAR 2 were overall lower because of the shallower water, but remained higher than outside the islands on a relative basis after 22 August as seismic surveying was allowed to continue inside the lagoon.

The 1/3-octave band level plots at AMARs 1 through 3 (Figures Figure 69, Figure 71 and Figure 73) cover the full monitoring period and do not therefore resolve the noise into pre- and post-22 August regimes. The persistence of the seismic survey activity inside the barrier islands is revealed, however, by the fact that the mean level at AMAR2 has a uniform offset compared to the 50th percentile in all frequency bands (Figure 71). At the two outer AMARs 1 and 3 (Figures Figure 69 and Figure 73), the mean level over the frequencies most affected by anthropogenic noise (about 50 Hz to 1 kHz) is significantly elevated relative to the 50th percentile as a result of the seismic survey activity having ceased in the later part of the monitoring period.

5. Summary and Conclusions

5.1. Airgun Array Sound Source Verification (SSV) and Vessel Sound Source Characterization (SSC)

JASCO performed acoustic measurements of a seismic trial as part of the Sound Source Verification (SSV) and Sound Source Characterization (SSC) components of the acoustic measurements study. Tables 20 and 21 present the maximum distances to 190, 180, 160, and 120 dB re 1 µPa threshold levels for each of the airgun source configurations. The distances obtained from measurements are based on the 90th percentile fits as described in Sections 3.1 and 3.2, and are the maxima over direction (broadside and endfire). The radius to the 190 dB re 1 µPa threshold for the 640 in^3 array was much larger than expected and exceeds the pre-season estimate by as much as 430%. In contrast, the 120 dB re 1 µPa threshold for the 640 in^3 array was the largest, but only 32% of the pre-season estimate.

Measured sound levels at close range tended to be higher than predicted by pre-survey modeling; the attenuation at longer ranges, however, was stronger than forecast and thus led to distant levels being lower than expected, particularly inside the barrier islands.

Table 22 presents the maximum distances to 160, 140, and 120 dB re 1 µPa threshold levels for each of the three vessels BP used to tow arrays. Pre-season modeling did not account for these vessels. The distances to threshold levels are relatively short, influenced primarily by the propagation conditions, with the 120 dB re 1 µPa threshold for the *Margarita*, the only propeller driven vessel, being the largest at 1151 m.

Table 20. *Outside barrier islands:* Maximum threshold distances for the mitigation airgun and two airgun arrays. Distances are maximized over direction and environment and are based on the 90th percentile fits.

90% rms SPL Threshold (dB re 1 µPa)	Outside Barrier Islands, 90th Percentile Distance (m)		
	640 in^3	320 in^3	40 in^3
190	516	360	24
180	1386	1134	158*
160	4616	4265	1602
120	14 163	13 313	9 221

*Actual maximum range from measurements.

Table 21. *Inside barrier islands:* Maximum threshold distances for the mitigation airgun and 320 in^3 airgun array. Distances are maximized over direction and environment and are based on the 90th percentile fits except as noted.

90% rms SPL Threshold (dB re 1 µPa)	Inside Barrier Islands, 90th Percentile Distance (m)	
	320 in^3	40 in^3
190	260	138
180	472	293
160	1545	933
120	5 700*	3 242

*Based on pre-season model estimate (actual range from measurements was 2528 m).

Table 22. Maximum threshold distances for the three vessels. Distances are maximized over direction and environment and are based on the 90th percentile fits.

90% rms SPL Threshold (dB re 1 µPa)	90th Percentile Distance (m)		
	Resolution, Outside Islands	*Margarita*, Outside Islands	*Storm Warning*, Inside Islands
160	1*	8**	2†
140	7*	73	12†
120	61	1151	134

*Extrapolated from minimum measurement range of 14.3 m.
**Extrapolated from minimum measurement range of 15.5 m.
†Extrapolated from a minimum measurement range of 60 m on departure.

5.2. Monitoring (Dipping Hydrophone)

JASCO provided BP with a dipping hydrophone system, which was deployed by BP's marine mammal observer (MMO) contractor HDR Inc during the period when the seismic survey was only conducted inside the barrier islands. No seismic pulses were detected in the recordings made by the system, and the observations were verified by the long-term AMAR recordings, which did not record pulses at matching times. These results show the shallow water environment inside the barrier islands severely attenuated pulses as they propagated through the sub-bottom and outside the barrier islands.

5.3. Monitoring (Long-Term)

JASCO used three Autonomous Multichannel Acoustic Recorders (AMARs) for long-term acoustic measurements over the entire seismic survey to determine the degree that the islands block seismic survey sound propagation.

By comparing the pulses between the single AMAR inside the islands with the two AMARs outside the islands, we found different results for sounds passing through the channel between the barrier islands and sounds passing directly through an island.

When the pulses travelled through the channel between islands, the pulse spectral density exceeded background levels at frequencies between 10 and 80 Hz, which indicates that the very shallow channel effectively prevented long-range water borne sound propagation. The detected low frequency energy propagated through the sub-bottom and reradiated energy back into the water column.

When the pulses travelled through an island, the pulse spectral density exceeded background levels at frequencies between 10 and 30 Hz. The detected low frequency energy propagated through the sub-bottom and reradiated energy back into the water column. The transmission loss was significantly greater for this path than for pulses travelling through the channel between islands.

The seismic survey contributed to the acoustic environment, which raised the 95th percentile levels above the expected prevailing noise levels, bringing the 75th percentile level close to the expected prevailing noise levels. The point at which the survey moved from outside the islands to inside is noticeable in the spectrograms. It isn't possible to compare these results to normal ambient conditions in the region due to the recording period only encompassing the survey time.

5.4. Transmission Through Barrier Islands

A comprehensive program that included pre-season modeling, a comprehensive SSV—both inside and outside the barrier islands—long-range opportunistic recordings, and long-term distributed recorders, resulted in a detailed understanding of the sound propagation from the OBC survey sound sources.

One of the primary questions this study aimed to answer was the way in which sound from survey activities inside the barrier islands was transmitted through the islands and into Harrison Bay. The 320 in^3 airgun array was the loudest source within the barrier islands (Table 21). The pre-season modeling estimated that the 120 dB mitigation radius for this source was 5700 m. The SSV measured this threshold as 2528 m in the endfire direction, whereas the broadside results based on sound level measurements at a maximum distance of 1800 m suggested an extrapolated range of over 16 km, which is well outside the perimeter of the barrier islands. Such an extrapolation, however, would have been inconsistent with the propagation conditions beyond the localized deeper region where the receivers had been deployed; this led to us disregarding the broadside results when assessing the 120 dB threshold distance.

This early interpretation, based on the SSV results alone, was later validated by analyzing the long-range and long-term measurements. Analysis of the long-range measurements did not detect pulses, whereas the long-term measurement data from the AMARs showed that at approximately 6 km from the 320 in^3 airgun array, which was operating inside the barrier islands, the received levels outside the islands only reached a maximum of 100 dB (90% rms SPL). This corroborated the decision made at the time of the SSV analysis to recommend adopting the pre-season modeled threshold distance of 5700 m as a conservative estimate of the 120 dB threshold radius for a sound source inside the islands.

The outcome of this study confirmed the validity of using three complementary measurement techniques to investigate the estimates provided by pre-season modeling. Although not all results fully agreed with the nature of acoustic propagation in Simpson Lagoon, they did contribute to the knowledge obtained through diverse approaches of investigating sound sources by providing more information on the significant sound attenuation properties of the shallow bathymetry and the barrier islands for seismic survey pulses emitted within the lagoon.

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Glossary

peak SPL

Maximum instantaneous sound pressure level, in a stated frequency band, within a stated time interval. Also referred to as zero-to-peak SPL. Unit, decibel (dB); symbol, L_{pk}.

peak-to-peak SPL

Difference between the maximum and minimum instantaneous sound pressure levels. Unit, decibel (dB); symbol, $L_{pk\text{-}pk}$.

rms

root mean square.

sound pressure level

See SPL.

SPL

sound pressure level. Ten times the logarithm to the base ten of the ratio of the time-mean-square pressure of a sound, in a stated frequency band, to the square of the reference pressure (ANSI S1.1-1994 R1999). Unit, decibel (dB); symbol, L_P. For sound in water, the reference sound pressure is one micropascal (1 μPa) and the unit for SPL is therefore written as "dB re 1 μPa".

$$L_P = 10\log_{10}\left(p^2 / p_o^2\right) = 20\log_{10}\left(p / p_o\right)$$

where p^2 is the time-mean-square sound pressure and p_o = 1 μPa is the reference sound pressure.

zero-to-peak SPL

See peak SPL.

Literature Cited

ANSI/ASA S1.6-1984. R2011. *American National Standard Preferred Frequencies, Frequency Levels, and Band Numbers for Acoustical Measurements.* American National Standards Institute and Acoustical Society of America, New York.

ANSI/ASA S12.64-2009/Part 1. 2009. *Quantities and Procedures for Description and Measurement of Underwater Sound from Ships–Part 1: General Requirements.* American National Standards Institute and Acoustical Society of America, New York.

Carnes, M.R. 2009. *Description and Evaluation of GDEM-V 3.0.* NRL Memorandum Report 7330-09-9165. US Naval Research Laboratory, Stennis Space Center, MS. 21 p.

Greene, C.R., Jr. 1997. Physical acoustics measurements. (3) In: Richardson, W.J. (ed.). *Northstar Marine Mammal Monitoring Program, 1996: Marine Mammal and Acoustical Monitoring of a Seismic Program in the Alaskan Beaufort Sea.* LGL Report 2121-2. Report from LGL Ltd. and Greeneridge Sciences Inc. for BP Exploration (Alaska) Inc. and the National Marine Fisheries Service (US).

ISO 266:1975. *Acoustics—Preferred Frequencies.* International Organization for Standardization, Geneva.

Malme, C.I., P.W. Smith, and P.R. Miles. 1986. *Characterisation of Geophysical Acoustic Survey Sounds*. Report by BBN Laboratories Inc. for Battelle Memorial Institute to the Minerals Management Service, Pacific Outer Continental Shelf Region.

McCauley, R.D., M.-N. Jenner, C. Jenner, K.A. McCabe, and J. Murdoch. 1998. The response of humpback whales (*Megaptera novaeangliae*) to offshore seismic survey noise: preliminary results of observations about a working seismic vessel and experimental exposures. *Australian Petroleum Production Exploration Association (APPEA) Journal* 38:692-707.

Ocean Studies Board. 2003. *Ocean Noise and Marine Mammals*. National Research Council (US), Committee on Potential Impacts of Ambient Noise in the Ocean on Marine Mammals. National Academies Press, Washington, DC. 192 p.

Teague, W.J., M.J. Carron, and P.J. Hogan. 1990. A comparison between the Generalized Digital Environmental Model and Levitus climatologies. *Journal of Geophysical Research* 95(C5):7167-7183.

Warner, G. and S. Hipsey. 2011. *Acoustic Noise Modeling of BP's 2012 Seismic Program in Simpson Lagoon* (*Harrison Bay, AK*): Version 2.0. Technical report for OASIS Environmental Inc. by JASCO Applied Sciences.

Wenz, G.M. 1962. Acoustic ambient noise in the ocean: Spectra and sources. *Journal of the Acoustical Society of America* 34:1936-1956.

Appendix A. Analysis

A.1. Ambient noise processing

Ambient sound levels at all recording stations were examined to document baseline underwater sound conditions. Ambient noise at each of these stations was analyzed by Hamming-windowed fast Fourier transforms (FFTs) with 1 Hz resolution and 50% window overlap. 120 FFTs performed this way were averaged to yield 1-min average spectra. These spectral density values (dB re 1 μPa$^{2\cdot}$s) are output for each minute to the analysis XML file.

Ambient sound levels at each analyzed recording station are extracted for the entire deployment period from the XML files and are presented as follows:

- Spectrograms of the 1-min average spectra computed as described above.
- Spectral level percentiles:
    5. Histograms of each frequency bin for all 1-min data from each recorder were computed.
    6. The 5th, 25th, 50th, 75th, and 95th percentiles were plotted. The 95th percentile curve describes the frequency dependent levels exceeded by 5% of the 1-min averages. Equivalently, 95% of the 1-min spectral levels are below the 95th percentile curve.

The 50th percentile (median of 1-min spectral averages) can be compared to the well-known Wenz ambient noise curves shown in Figure 9. The Wenz curves show ranges of variability of ambient spectral levels as a function of frequency based on measurements worldwide over a range of weather, vessel traffic, and seismic conditions. The Wenz curve data are general and are used for approximate comparisons only.

The one minute averaged, 1 Hz spectral density levels are also summed over the 1/3-octave and decade bands to obtain one-minute broadband levels as dB re 1 μPa. These values are output to the XML files and then collapsed over the entire deployment to create a single CSV file for each recorder. These values are available to stakeholders on request. The third octave center frequencies are shown in Table 23

Table 23. Third octave bands.

Band	Nominal Center Freq.	Lower Frequency	Upper Frequency
1	10	8.9	11.2
2	13	11.6	14.6
3	16	14.3	17.9
4	20	17.8	22.4
5	25	22.3	28.0
6	32	28.5	35.9
7	40	35.6	44.9
8	51	45.0	57.2
9	64	57.0	71.8
10	81	72.0	90.9
11	102	90.9	114.4
12	128	114.1	143.7
13	161	143.4	180.7
14	203	180.8	227.9
15	256	228.0	287.4
16	323	287.7	362.6
17	406	362.7	455.7
18	512	456.1	574.7
19	645	574.6	723.9
20	813	724.2	912.6
21	1024	912.3	1149
22	1290	1150	1447
23	1625	1448	1824
24	2048	1824	2297
25	2580	2298	2896
26	3251	2896	3649
27	4096	3649	4597
28	5161	4598	5793
29	6502	5793	7298
30	8192	7298	9195
31	10321	9195	11585
32	13004	11585	14597