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OBN Marine Seismic Survey

PSO & PAM Report

Marine Seismic Survey

EPI Report No. E2174

Client	Murphy Exploration and Production Company
Area	Green Canyon, Ewing Banks - U.S. Gulf of Mexico
Survey	3D OBN Seismic Survey
Permit No	L23-033
Contract No	E002174
Dates	October 30, 2024 – January 21, 2025
Contractor	PXGEO US Inc
Vessel	MV Artemis Athene

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1.0 Executive Summary

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1.1. Overview

Murphy Exploration and Production Company -USA (Murphy) contracted PXGEO US Inc. (PXGEO) to conduct a 3D multi-component Ocean Bottom Node (OBN) survey, in the U.S. Gulf of Mexico (GOM), located within Green Canyon protraction area in water depth ranging from 900 meters to 1350 meters. The program was conducted in federal waters of the GOM located within Green Canyon block area. Protected species monitoring was conducted in accordance with the Bureau of Ocean Energy Management (BOEM) and National Marine Fisheries Service (NMFS) standards, as well as Geophysical Survey Plan Approval Conditions for Lease Outer Continental Shelf (OCS) Permit L23-033. PXGEO mobilized two vessels for this project. The *Havila Subsea* as the node handling vessel and the Research Vessel (RV) *Artemis Athene* as the sole source vessel. This report is the Final Protected Species Report for the 3D OBN Survey, where the protected species monitoring and seismic survey operations were undertaken by the RV *Artemis Athene*. The program took place from 30 October 2024 to 21 January 2025.

Murphy and PXGEO adopted the best practice approach by adopting guidelines for the mitigation of protected species over the span of this project. The Client and Vessels operated under the regulatory guidelines jointly stipulated by the NMFS Biological Opinion on the Federally Regulated Oil and Gas Program Activities in the Gulf of Mexico, BOEM, Bureau of Safety and Environmental Enforcement (BSEE), U.S. Environmental Protection Agency as well as additional guidelines outlined in the Letter of Authorization (LOA) and the Environmental Management Plan (EMP).

Throughout the reporting timeframe, three trained visual Protected Species Observers (PSO) and four Passive Acoustic Monitoring (PAM)s, contracted through EPI Group remained on board the RV *Artemis Athene* to uphold the regulatory guidelines and reporting requirements. The PSOs/PAMs were certified by BOEM and had previous survey experience. Mitigation measures were implemented to minimize potential impacts to marine mammals and sea turtles throughout the duration of the survey. The mitigation protocols for this survey included the establishment of buffer zones (BZ) and exclusion zones (EZ) around the acoustic sound source to create a reasonable separation distance in regard to the protected species, conducting visual and acoustic monitoring consistently for 24 hours, determining and implementing delays of the sound source initiation based on the animals' distance to their relevant buffer and exclusion zones, and executing shutdowns or vessel strike avoidance (VSA) maneuvers if necessary to ensure protection to all animals and to maintain regulatory compliance.

Please refer to the report summary below and Table 1 for details on observation data for the source vessel.

Artemis Athene (Table 1): There were 11 mitigation actions and zero non-compliance issues for the duration of the project. In total, there were 15 acoustic detections and 11 visual sightings.

Table 1: Murphy 3D OBN Report Overview

REPORT OVERVIEW
There were 84 survey days beginning 30 October 2024 to 21 January 2025
Visual observation time totaled 906:16 and acoustic monitoring time totaled 1442:58.
The total number of seismic source sequences from the first production day to last was 357 (36 test sequences and 321 full volume sequences).
Seismic source was active for a total of 1172:28 for the duration of this survey.
There were 11 visual sightings.
There were 15 acoustic detections.
There were 11 mitigation actions required for this survey period.
There were 0 non-compliance issues.

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2.0 Introduction

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2.1. Project Information

The RV *Artemis Athene* undertook the 3D OBN seismic survey that was conducted by PXGEO on behalf of Murphy. The survey took place in deep waters within the Green Canyon and Ewing Bank US Gulf of Mexico.

The 3D seismic acquisition area was approximately 769.49 km^2 with a greater working area of 1023.14 km^2 around it to allow for vessel line turns, equipment deployment and recovery, and source testing. Water depths during the program ranged from 900 meters to 1350 meters.

The objectives during this survey were to collect data to support: site characterization, development of a ground model, ensure the seabed is clear of any obstructions, and proper identification of buried archaeological features in compliance with the NMFS Biological Opinion on the Federally Regulated Oil and Gas Program Activities in the Gulf of Mexico, BOEM, Bureau of Safety and Environmental Enforcement, U.S. Environmental Protection Agency as well as additional guidelines outlined in the LOA and the EMP.

The survey is a shooting methodology where nodes are rolled, and source operations are conducted centrally within the active node patch. The working prospect survey area covers approximately 769.49 km^2, with the greater working area covering approximately 1023.14 km^2.

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2.2. Location Map

The location of the acquisition area and greater working area in relation to the US coast in the Gulf of Mexico is shown in Figure 1. Figure 2 represents the shooting nodes design.

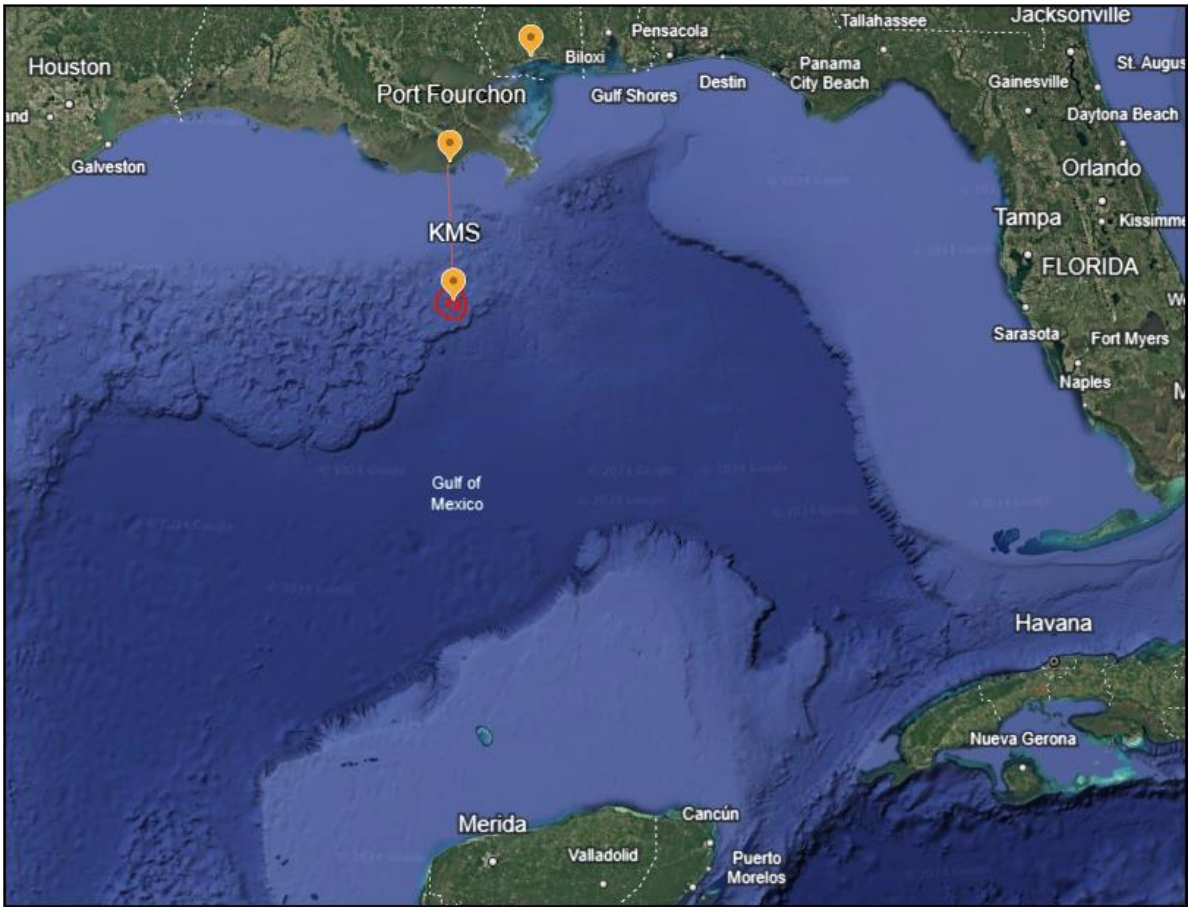

Figure 1: Survey General Location Map

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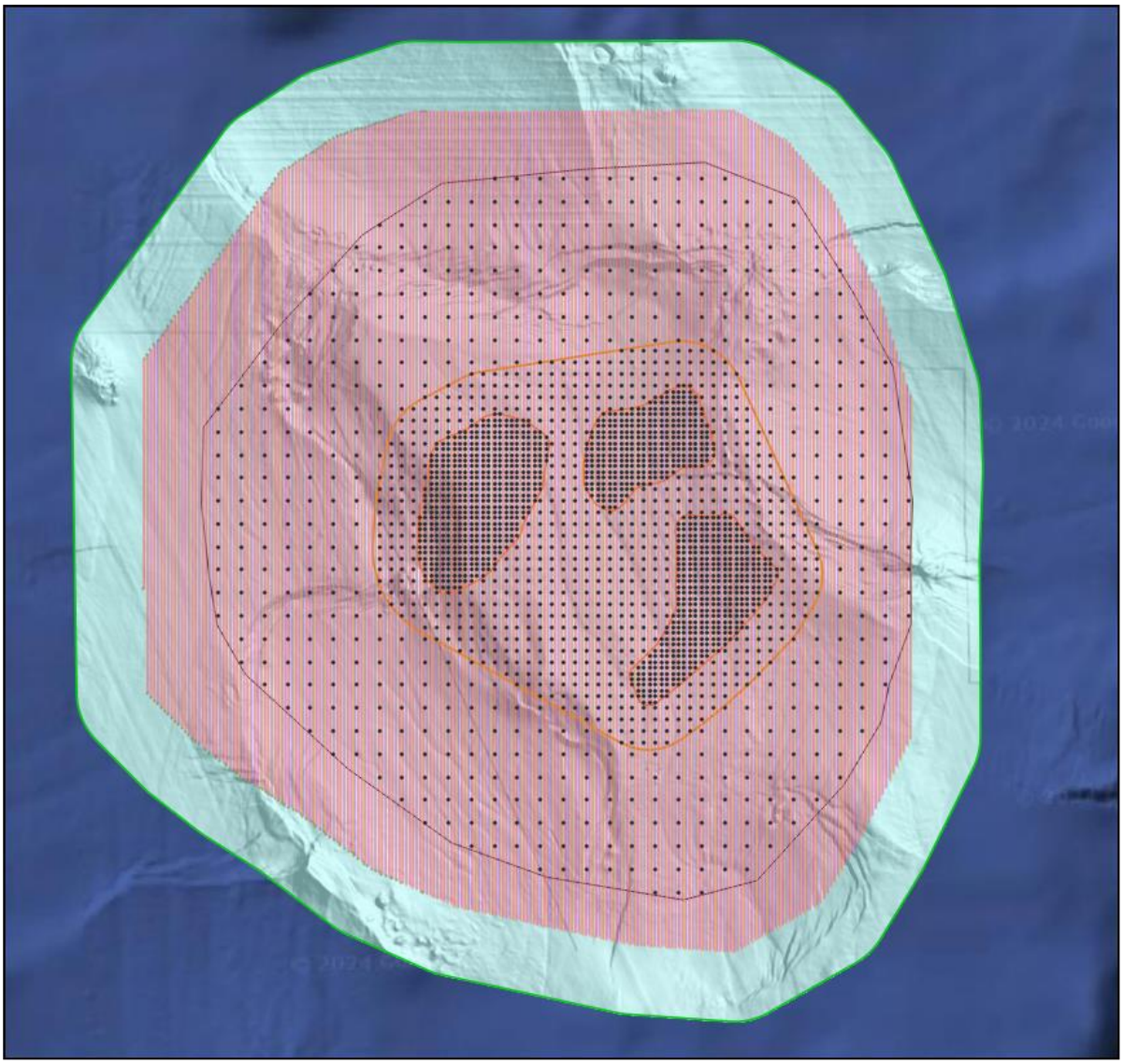

Figure 2: Node and source polygons: (Node locations in blue - Source polygon in pink)

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3.0 Vessels & Equipment

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3.1. Vessels on Survey

The RV *Artemis Athene* was the source vessel for the project (**Figure 3**: RV *Artemis Athene*).

3.1.1. Source Vessel

ARTEMIS ATHENE

Classification: Source Vessel	Flag: Norway (NO)
IMO: 8805626	Call Sign: LDIA3
MMSI: 257156000	Length X Breadth: 91.6 x 18m

Figure 3: RV *Artemis Athene*

3.1.2. Node Vessel

Havila Subsea was the dedicated node vessel for this project. The node vessel was equipped with dual ROV's with a minimum node inventory of 3000 MANTA nodes.

HAVILA SUBSEA

Classification: Offshore Supply Ship	Flag: Norway
IMO: 9505508	Call Sign: LGSY3
MMSI: 259073000	Length X Breadth: 98m x 19,80m

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Figure 4: Node Vessel *Havila Subsea*

3.2. Seismic Equipment and Sound Emissions

The diagram below shows the towing and source array configurations for the *Artemis Athene* (Figure 5). The survey was conducted using a total of 84 source elements. Each source was made up of two sub-arrays where each sub-array was equipped with 14 source elements, varying in volume from 80 to 320 cubic inches. At full power, the three source sub-arrays operated at a pressure of 2,000 psi and a volume of 5,000 cubic inches. Individual source elements ranged in volume from 80 to 320 cubic inches. Soft starts were conducted under the agreed guidelines and had a duration of 23 to 24 minutes.

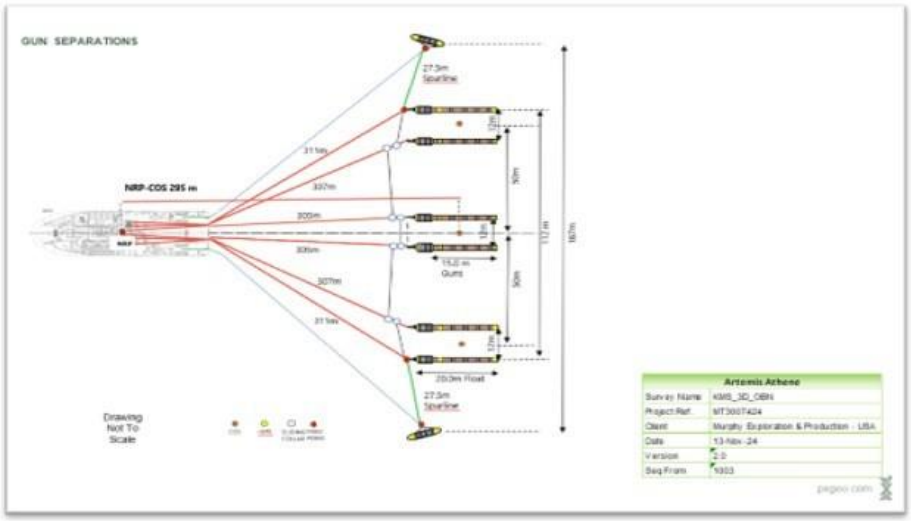

Figure 5: Towing and source array configurations

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4.0 Operations

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4.1. Record of Operations

The RV *Artemis Athene* began the survey for Green Canyon OBN on 03 November 2024 with data acquisition beginning 12 November and completed data acquisition on 19 January 2025. There was a total of 84 survey days and a total of 69 data acquisition days (source was active). Of the 84 survey days, the vessel was at sea and visual monitoring was conducted for 81 days. The remaining days (3) were spent alongside in Gulfport, MS. A summary of events is detailed below.

The vessel was at sea at the commencement of the project and went on standby for node deployment. Between 03 and 04 November, the vessel conducted a series of test lines to troubleshoot the configuration of the source. On 04 November it began transit to Gulfport, MS for crew change and a port call and was alongside on 05 November. It departed Gulfport on 09 November and began data acquisition on 12 November. The vessel was then in steady production besides two inclement weather events which occurred between 11 and 12 of December and 05 and 07 of January. The vessel completed acquisition on 19 January and was alongside in Gulfport, MS on 21 January for demobilization.

During daytime hours, pre-survey watch periods and clearance were done by both visual observations and PAM monitoring. At night, pre-survey watch periods and clearance were done by PAM monitoring only. Figure 6 portrays the number of pre-survey watches conducted during daytime vs. night-time. There were 185 pre-survey watches conducted by visual observation and PAM monitoring during daylight hours versus 172 conducted by PAM only during night-time hours.

During this survey the number of soft starts conducted during the day was 157 and the number of soft starts conducted at night was 164. The number of tests conducted during the day was 23 and the number of tests conducted at night was 13. Figure 7 compares the number of soft starts and source tests during the day versus at night.

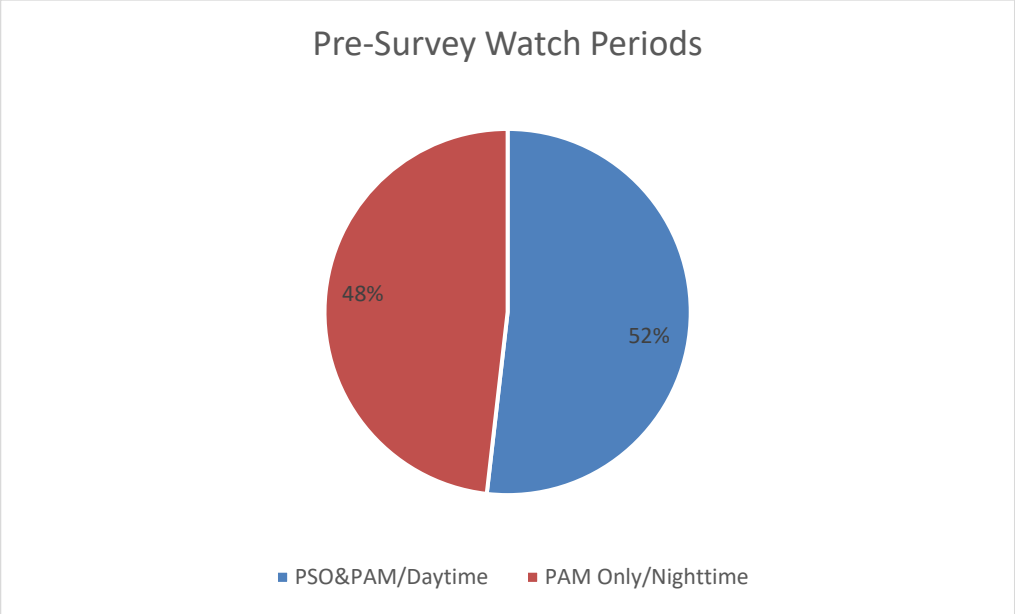

Figure 6: Number of Daytime (PSO & PAM) vs. Night-time (PAM only) pre-survey watch periods

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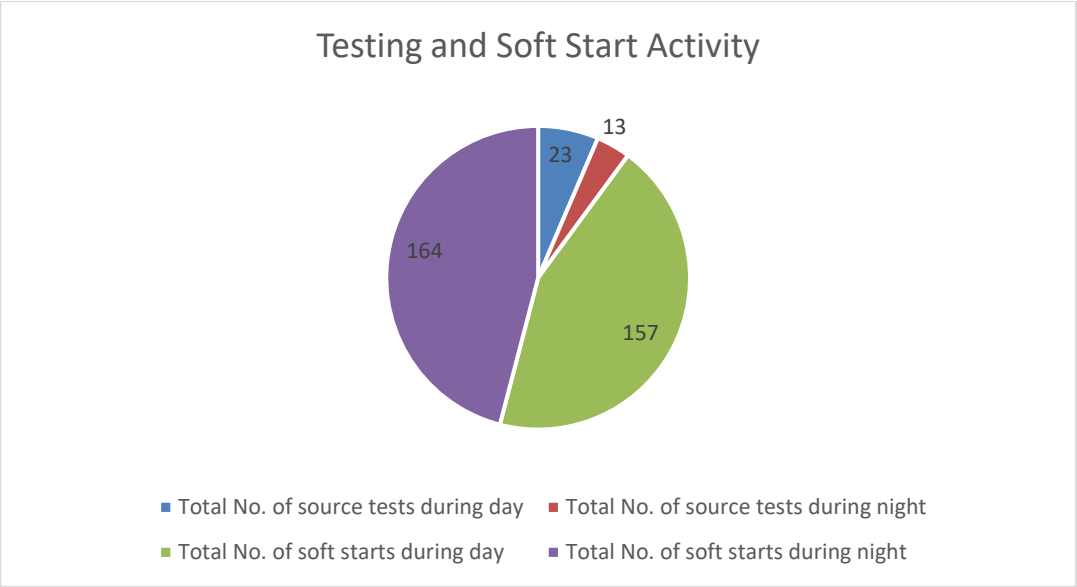

Figure 7: Number of soft starts and source tests during day and night

Communication between PSOs/PAM Operators and seismic crew was practiced and maintained over VHF radios and occasionally directly between survey crew and PAM operators. Protocol for communication began with a radio check between survey crew and PSO/PAM operators well in advance of any testing that was planned to begin. Protocol for initiation of the source began with survey crew calling PSO/PAM operators for clearance before any activation of the source, and survey crew waited for an "all clear" response from the applicable PSO/PAM operators. Survey crew also informed PSO/PAM operators when the source went silent for any reason, and when a survey line had ended but the source remained active for recording purposes.

The record of operations forms in **Appendix A** details the operations which took place during this reporting period.

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5.0 Mitigation Measures

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5.1. Protected Species Mitigation Action Procedures

To minimize the potential impacts of seismic operations on certain protected species, including marine mammals and sea turtles, BOEM, NMFS, and BSEE, have outlined monitoring, mitigation, and reporting procedures that survey operators and permit holders are expected to implement during their seismic survey operations. Protected species monitoring, mitigation, and reporting procedures that are applicable to the 3D OBN Survey are contained in the following regulatory documents:

1. The Biological Opinion issued by the NMFS on March 13, 2020
2. The survey permit issued by BOEM, permit L24-011.
3. The LOA issued by NMFS

PSOs established and monitored the applicable BZ and EZ, depending on the species and source activity status, as shown in Table 2. These zones were based upon the radial distance from the edges of the source array.

During use of the acoustic source (i.e., anytime the acoustic source was active, including ramp-up), occurrence of protected species within the relevant BZ (but outside the EZ) was communicated to the operator to prepare for the potential shutdown of the acoustic source (when required).

Table 2: Established exclusion and buffer zone distances.

Species / Species Group	Separation distance	Buffer Zone	Exclusion zone
Rice's whale, beaked whale, *Kogia* species	500 m	1500 m	1500 m
Sperm whale	100 m	1500 m	1500 m
All other marine mammals	50 m	1000 m	500 m [1]
Sea turtles	50 m	1000 m	100 m [2]
ESA-listed fish (Gulf sturgeon, oceanic, white-tipped shark, giant manta ray)	50 m	N/A	N/A

1. Shutdown is not required for dolphins of the following genera: *Steno, Tursiops, Stenella,* and *Lagenodelphis. (*rough-toothed dolphin, bottlenose dolphin, Atlantic spotted dolphin, pantropical spotted dolphin, spinner dolphin, Clymene dolphin, striped dolphin, Fraser's dolphin*)*
2. Turtles inside 100 m - implement 7 shot turtle pause to allow 200m from array upon resumption of source activity.

5.1.1. Vessel Strike Avoidance Mitigation

The PSOs maintained a continuous watch during daylight hours to ensure the vessel maintained a safe distance from protected species while the vessel was in production or in transit. There were no observations of vessel strikes for the duration of the project. When protected species approached the vessel, such as bow riding dolphins, abrupt changes in course were avoided as to not disturb the animals. The vessels operated at an average speed of 4.3 knots during operations and less than 10 knots during periods of transit, which allowed time for marine mammals and/or sea turtles to avoid the vessel's path. Accordingly, support vessels on the project typically operated at speeds below 10 knots.

5.2. Survey Equipment Subject to Mitigation

All the survey equipment that produces sound below 200 kHz was subject to the following monitoring and mitigation protocols with the exception of the USBL, which is considered to be navigational equipment.

5.3. Buffer Zones & Exclusion Zones

Two types of zones were established around the seismic sources, both with radii that extended from the outer edge of the source array.

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Buffer Zones (BZ): Applicable during the pre-clearance search periods conducted prior to initiating the sound source from silence, where detections of a protected species inside its applicable BZ during the search resulted in a delay activating the source:

- 1500 meters: All true whale species (i.e. Rice's whale, sperm whales, *Kogia* species, and all beaked whales)
- 1000 meters: All other marine mammals and sea turtles

Exclusion Zones (EZ): Applicable once the source has been activated, where detections of a protected species inside its applicable EZ resulted in a shutdown of the sound source:

- 1500 meters: All true whale species (i.e. Rice's whale, sperm whales, *Kogia* species, and all beaked whales)
- 500 meters: All other marine mammals
- 100 meters: A 7-shot turtle pause shall be implemented for any turtles within 100 meters of the ship, such that the turtle is greater than 200 meters from array upon resumption of source activity.

5.4. Mitigation Measures

Visual monitoring of protected species is a standard procedure during seismic surveys in the Gulf of Mexico since 2002. During the seismic operations and transiting phases of the project, the client and contractor adhered to the mitigation protocols as outlined in the NMFS Biological Opinion of 2020, the survey permit issued by BOEM, the NMFS issued LOA, and the EMP. The mitigation measures are summarized in Table 3.

Table 3: Summary if mitigation measures

Source mitigation zone	1500 meters - All true whales 500 meters - Other marine mammals 100 meters - Sea turtles
Pre-watch period	30 minutes of consecutive monitoring 2 PSO's and 1 PAM operator during daylight 1 PAM operator during nighttime or reduced visibility
Soft start length	20 minutes
Soft start delays	15 minutes (Delphinid spp.) 30 minutes all other marine mammals and sea turtles
Shut down during full volume source	Any marine mammal detected in their exclusion zone (except for four delphinid genera)
Shutdown during Soft start	Any marine mammal detected in their exclusion zone with no exceptions
Turtle pause	7 turtle-pause shots allowed for turtles inside their exclusion zone
Vessel Strike Avoidance	500 meters – All true whales 100 meters – Sperm whale 50 meters – All other marine mammals
Applicable species	Marine mammals and sea turtles

5.4.1. Pre-clearance

To activate the sound source, a search period of at least 30 minutes was conducted.

- During the daytime (30 minutes before sunrise to 30 minutes after sunset), the search was conducted visually by the PSOs and acoustically by the PAM operator.
- During nighttime, the PAM operator conducted the search acoustically.
- The PSO and PAM operator on watch would be notified of the intent to turn on the source from silence, either to conduct a ramp-up or for testing, at least 60 minutes prior to the planned start.

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5.4.2. Delays to Activation of the Acoustic Source

If any marine mammal or sea turtle was detected inside its respective BZ during the 30-minute search period, initiation of the seismic source was delayed until:

- All marine protected species that were observed inside the relevant BZ were confirmed by the visual observer to have exited the relevant BZ.
- 15 minutes passed from the last observation for small odontocetes if not observed exiting the BZ
- 30 minutes passed from the last detection for all other protected species, including sea turtles, if not observed exiting the BZ
- 30 minutes passed from the last detection for acoustic-only detections.

5.4.3. Ramp Up & Testing Procedures

The intent of ramp-up is to warn marine mammals and sea turtles of pending seismic operations and to allow sufficient time for those animals to leave the immediate vicinity. For all acoustic source activity, including source testing involving more than one source element, ramp-up procedures were conducted to allow marine mammals and sea turtles to depart the exclusion zone before surveying begins.

- The vessel tested a single source element or cluster without ramp-up regardless of volume. If using more than a single cluster, ramp-up was required from the smallest volume source element to the size needed for testing.
- In order to minimize the time the sound source was active, ramp-up was planned for immediately before the start of the survey. Seismic source activation only occurred at times of poor visibility (including night) where operational planning could not reasonably avoid such circumstances.
- Ramp-up procedures were as follows:
  - Visually and acoustically (day) or acoustically (night) monitor the BZ and adjacent waters for the absence of marine mammals and sea turtles for at least 30 minutes before initiating ramp-up procedures.
  - Seismic personnel confirmed with the PSOs on watch (daytime) and/or the PAM operator (day and night) that the BZs were clear of protected species.
  - If no protected species were visually or acoustically detected inside their respective BZs, ramp-up procedures began. If animals were detected, procedures were followed to clear the BZs prior to start of source operations.
  - Ramp-ups began by activating a single source element of the smallest volume in the array.
  - Ramp-ups continued in stages by doubling number of active elements at the commencement of each stage, with each stage being approximately the same duration.
  - Total duration of the ramp-up averages 23 to 24 minutes

5.4.4. Shutdown Due to Protected Species

Shutdown During Ramp-Up

If any marine mammal or sea turtle was visually or acoustically detected within its EZ, an immediate shutdown of the seismic source in ramp-up was required.

1. No shutdown of the ramp-up was required for marine mammals or sea turtles detected inside the BZ during ramp-up; however, notifications were made that a shutdown could be called for if those animals moved into the EZ.
2. No shutdown of the ramp-up was required for acoustic-only detections (day or night) unless those acoustic-only detections could be localized inside the appropriate EZ. Notification should still was made that a shutdown could be called for if the animals were able to be localized.

5.4.5. Shutdown During Full Volume Operation

If **any marine mamma**l is detected visually or acoustically within its EZ, an immediate shutdown of the seismic source is required. The shutdown requirement is waived under the following circumstances:

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1. Shutdown was not required for dolphins of the following genera: *Steno, Tursiops, Stenella*, and *Lagenodelphis* (this only applies at full volume, not ramp-up).
2. Shutdown was not required for acoustic detections of delphinids inside the EZ unless the PSO or PAM operator could confirm the dolphin(s) present were from a different genus than those listed above.

If there was uncertainty, visual PSOs would use their best professional judgment in making the decision to call for a shutdown. Such instances included determining if the animal belonged to one of the delphinid genera for which shutdown was waived, or if it was a species with a larger EZ.

The vessel operator complied immediately with any shutdown request made by a PSO or PAM operator. Any discussion occurred only after the shutdown was implemented.

Subsequent restart of the seismic source only occurred following clearance of the EZ of all marine protected species under the following conditions:

- All marine mammals were visually confirmed by the PSO exiting the relevant EZ (not BZ), OR
- When a marine mammal was not observed exiting the EZ, an additional 30 minutes had elapsed following the last detection inside the EZ.

All resumptions of source activity following a protected species shutdown began with a ramp-up.

Silent Periods in Source Operation During Daylight

As occasional short periods of silence were required for reasons other than mitigation, the seismic source was silenced for periods of time not exceeding 30 minutes, then restarted at the same volume for operations without a ramp-up if:

- Visual and acoustic monitoring was continued diligently through the silent period, AND
- No marine protected species were visually observed in their respective EZ during the silent period, and no acoustic detections were made at any distance.

Procedures for returning to full volume without ramp-up after silent periods also applied to returning to full volume from reduced volume. However, if the source was operating at a reduced volume for more than 30 minutes, a ramp-up was required to return to full volume.

Silent Periods in Source Operation During Night and Reduced Visibility

As occasional short periods of silence were required for reasons other than mitigation, the seismic source was silenced for periods of time not exceeding 10 minutes, then restarted at the same volume for operations without a ramp-up if:

- Acoustic monitoring was continued diligently through the silent period, AND
- No acoustic detections were made at any distance.

Non-Production Source Testing & Miscellaneous Source Operation

The acoustic source was deactivated when not acquiring data or preparing to acquire data, except as necessary for testing. Unnecessary use of the acoustic source was avoided.

5.4.6. Vessel Strike Mitigation

The PSOs maintained a continuous watch during all daylight hours to ensure the vessel maintained a safe distance from protected species, both while the vessel was in production or in transit. Vessels are not required to shift into neutral for animals that approach the vessel voluntarily. Separation distances established are as follows:

- 500 m: All baleen whales including the Rice's whale (formerly known as the Bryde's whale)
- 100 m: Sperm whales
- 50 m: All other marine mammals (including manatees), sea turtles, and ESA-listed fish species.

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Any large whale for which a species could not be identified was treated as a baleen whale.

There were no observations of vessel strikes for the duration of the project. When protected species approached the vessel, such as bow riding dolphins, abrupt changes in course were avoided as to not disturb the animals. The speed at which the vessel was operating was well under 10 knots, and therefore, allowed time for marine mammals and/or sea turtles to avoid the vessel path (NOAA, 2008).

Vessel Speed Restrictions
Vessel speeds must be reduced to 10 knots or less when mother/calf pairs, pods, or large assemblages (greater than three) of any marine mammal were observed near a vessel.

Vessel Separation Distances
When protected species were sighted while the vessel was underway, the vessel took action as necessary to avoid violating the relevant separation distance (e.g. attempt to remain parallel to the animal's course and avoid excessive speed or abrupt changes in direction until the animal has left the area).

If marine protected species were sighted within the relevant separation distance, the vessel would reduce speed and shift the engine to neutral, not engaging the engines until animals were clear of the area. While Appendix C of the NMFS Biological Opinion states that this does not apply to any vessel that is towing gear, an effort was still made by the vessel, as was operationally feasible, to maintain a separation distance. PSOs provided suggestions for VSA, then allowed the vessel crew to determine whether that procedure could be executed without risk to the safety of the vessel and crew.

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6.0 Observations

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6.1. PSO/PAM Operator Monitoring Effort

During this reporting period, the PSOs maintained watch from the bridge, bow deck, and helideck to obtain a 360-degree view of separation distance zones and eventual buffer and exclusion zones (Figure 8). The PAM operators conducted operations from the instrument room on the forecastle deck. Visual observations for protected species were conducted during daylight hours, from 30 minutes prior to sunrise until 30 minutes post sunset for all daytime source activities. Acoustic observations for marine mammals were conducted at least 30 minutes prior, during, and at least one hour after all source activity day or night.

The cumulative visual and acoustic observations effort was 2349 hours and 14 minutes. These efforts are depicted in Figure 9 and recorded in the Location and Effort Form located in APPENDIX A. Total visual observation effort was 906 hours and 16 minutes. Of this time, 557 hours and 12 minutes were spent conducting visual observations while the source was active and 349 hours and 04 minutes while the source was silent (Figure 10). Total acoustic observation effort was 1442 hours and 58 minutes. Of this time, 1172 hours and 28 minutes were spent conducting acoustic observations while the source was active and 270 hours and 30 minutes while the source was silent (Figure 11).

Figure 8: PSO with 25 x 150 Fujinon Big Eye Binoculars

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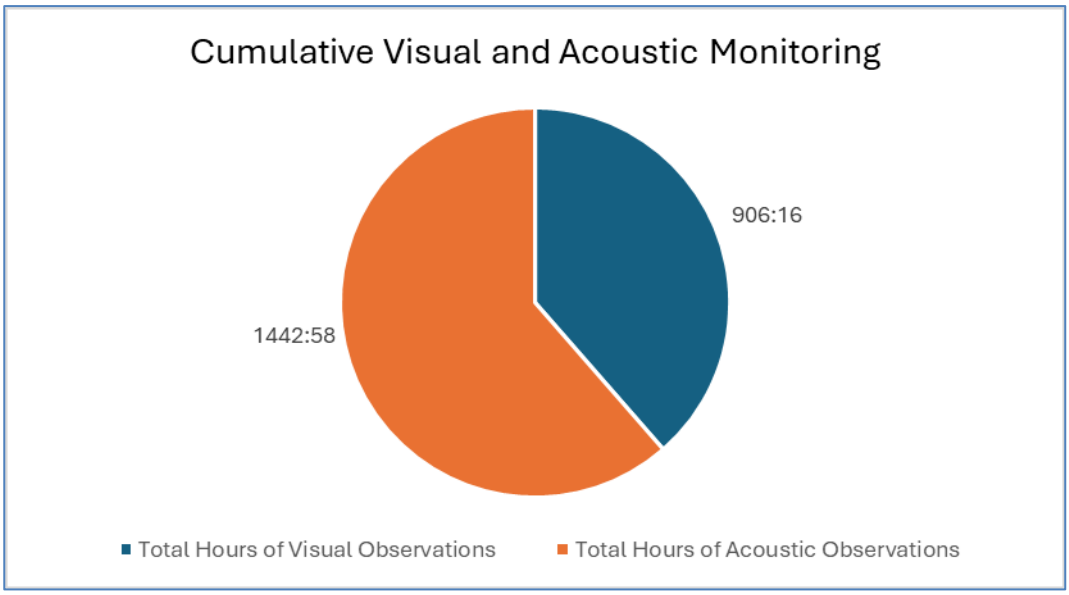

Figure 9: Total hours of visual vs Acoustic Observations in 2349:14 hours

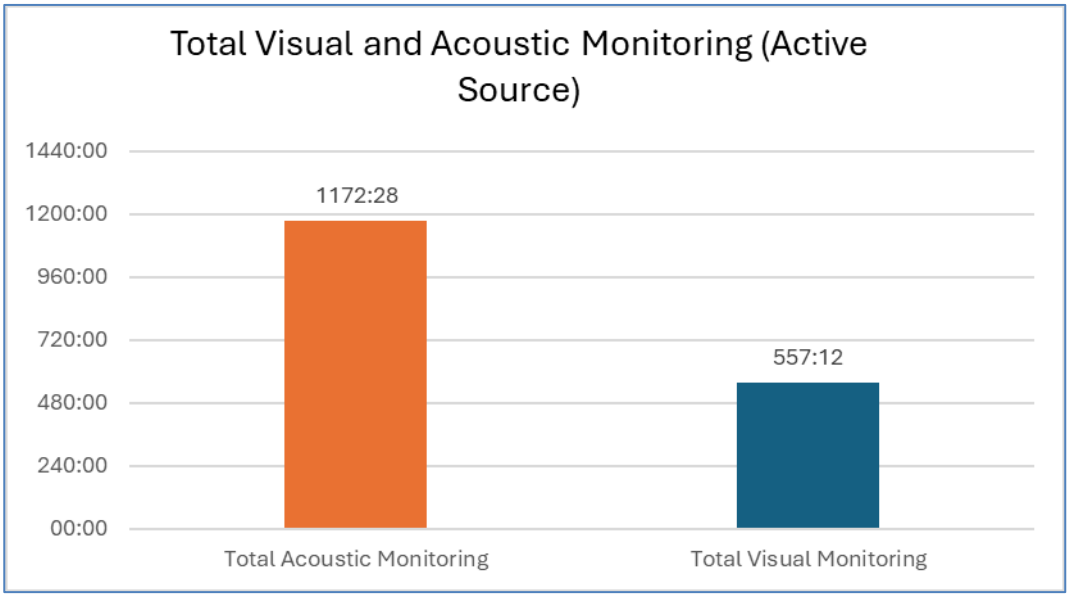

Figure 10: Total Visual and Acoustic Monitoring (Active Source) in 1729:40 total

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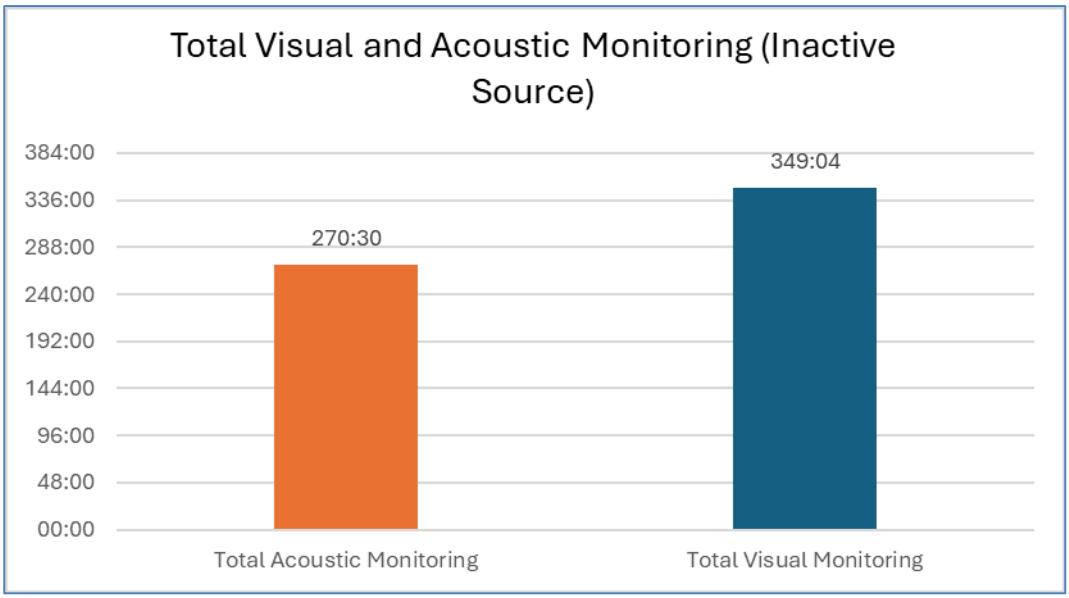

Figure 11: Total Visual and Acoustic Monitoring (Silent Source) in 616:21 total

6.2. Sighting and Detection Summary

There was a total of 11 visual sightings and 15 acoustic detections throughout this survey, of which one sighting of an unidentified dolphin occurred concurrently with an acoustic detection. Visual sightings included sperm whales (*Physeter macrocephalus*), short-finned pilot whales (*Globicephala macrorhynchus*), common bottlenose dolphins (*Tursiops truncatus*), unidentified dolphins, leatherback sea turtles (*Dermochelys coriacea*), and unidentified sea turtles (Table 4). All acoustic detections were of unidentified dolphins (Table 5). Visual sightings while the source was at full volume included a total of two whale detections and one dolphin detection. In addition, a total of six dolphin sightings and two sea turtle sightings were made while the source was silent. Detection rates for these instances can be found in Table 6. Acoustic dolphin detections included three while the source was at full volume, two while the source was in soft start, and 10 while the source was silent. Detection rates for these instances can be found in Table 7. Overall, the closest point of approach (CPA) for visual detections was 325 meters while the source was silent and 1435 meters while the source was active (Figure 12). For acoustic detections, the CPA was 470 meters while the source was silent and 480 meters while the source was active (Figure 12).

Table 4: Visual sighting summary with detection rates for each species and species group

Species	Total No. Visual Sightings	Total No. of Animals	Detection rate (%)
Sperm whale	2	2	0.22%
Total Whales	**2**	**2**	0.22%
Bottlenose dolphin	4	28	0.44%
Short-finned pilot whale	1	11	0.11%
Unidentified dolphin	2	4	0.22%
Total Dolphins	**7**	**43**	0.77%
Unidentified sea turtle	1	1	0.11%
Leatherback sea turtle	1	1	0.11%
Total Sea Turtles	**2**	**2**	0.22%
Total Visual Sightings	**11**	**47**	1.21%

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Table 5: Acoustic detection summary with detection rates for each species and species group

Species	Total No. Acoustic Detections	Total No. of Animals	Detection rate (%)
n/a	0	0	0.00%
Total whales	**0**	**0**	0.00%
Unidentified dolphins	15	42	1.04%
Total dolphins	**15**	**42**	1.04%
Total Acoustic Detections	15	42	1.04%

Table 6: Visual detection rates across all source activities

Group	Full Volume	Soft Start	Reduced Volume	Silent
Whales	0.22%	0.00%	0.00%	0.00%
Dolphins	0.11%	0.00%	0.00%	0.66%
Sea Turtles	0.00%	0.00%	0.00%	0.22%
Total	0.33%	0.00%	0.00%	0.88%

Table 7: Acoustic detection rates across all source activities

Group	Full Volume	Soft Start	Reduced Volume	Silent
Whales	0.00%	0.00%	0.00%	0.00%
Dolphins	0.21%	0.14%	0.00%	0.69%
Total	0.21%	0.14%	0.00%	0.69%

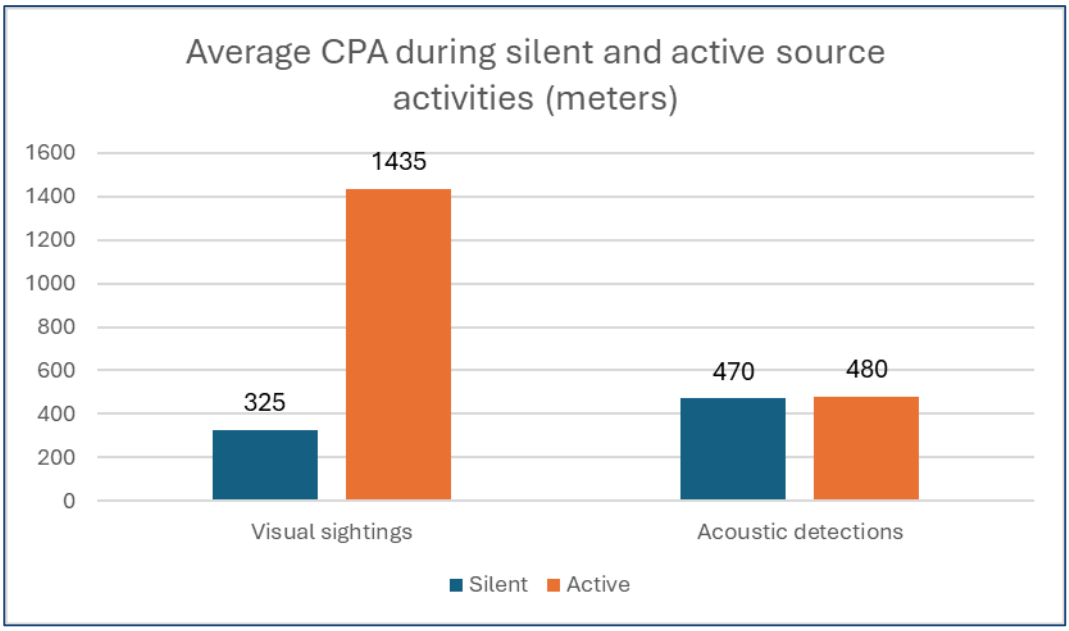

Figure 12: Average CPA during silent and active source activities

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6.3. Visual Survey Methods

6.3.1. Marine Mammal and Sea Turtle Sightings

During this project, the PSO team conducted a total of 906 hours and 16 minutes of visual monitoring and recorded the following 11 visual sightings:

VS #1: On 5 November 2024, at 13:03 UTC, two juvenile common bottlenose dolphins (Figure 13) were sighted 40 meters from the vessel's starboard bow, at a bearing of 35 degrees with a heading of 300 degrees. The dolphins were seen surfacing towards the vessel at a moderate pace. During the sighting the vessel was travelling through the port's channel while in transit to port, and in this transit, several more dolphins were sighted surfacing in variable bearings and headings, for a total count of 11 dolphins. At 14:20 UTC the last dolphin was sighted 60 meters from the vessel's starboard side, at a bearing of 100 degrees, with a heading of 350 degrees. The CPA the dolphins made to the vessel was six meters at 13:10 UTC. Since the dolphins entered the separation distance voluntarily, no strike avoidance maneuvers were necessary, however, the vessel-maintained course and speed under 10 knots throughout the sighting as a vessel strike avoidance action. No mitigation actions were necessary since the source was not deployed.

Figure 13: Visual Sighting 1 - Bottlenose dolphins

VS #2: On 22 November 2024, at 17:17 UTC, while the source was silent and the vessel was on a line change, an unidentified sea turtle was sighted five meters abaft of the starboard beam at a bearing of 110 degrees and heading of 25 degrees. The CPA to the vessel was five meters. The unidentified sea turtle was 300 meters from the silent source. The sea turtle surfaced, floated atop the water briefly, and then dove underneath. The sea turtle was last seen at 17:18 UTC five meters abaft of the starboard beam, 300 meters from the silent source, at a bearing of 110 degrees, and heading of 25 degrees. The closest approach the sea turtle made to the silent source was 300 meters at 17:17 UTC. The sea turtle was sighted within the buffer zone of 1000 meters during pre-clearance and not seen leaving the buffer zone, therefore a mitigation delay of 30 minutes was implemented before initiating soft start. The total mitigation down time was 30 minutes as the sighting occurred just as the PAM operator was about to call to initiate soft start.

VS #3: On 27 November 2024, at 14:51 UTC, a single sperm whale was sighted blowing at a bearing of 30 degrees at a distance of 2500 meters to the vessel and 2850 meters to the acoustic source. The whale was traveling away from the vessel, towards the northeast and was last observed at 15:06 UTC. At the time of the sighting the vessel was at full power on a production line, with a CPA of 2850 meters to the acoustic source at 14:51 UTC. The whale did not enter the exclusion zone or VSA separation distance, with no mitigation actions required.

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Figure 14: Visual Sighting 3 - Sperm whale flukes. Photo credit: Izchel Gomez.

VS #4: On 27 November 2024, at 15:38 UTC, a single sperm whale was sighted blowing 1700 meters off the vessel's beam on the starboard side. The whale was stationary. The whale was oriented to the east. At the time of the sighting the vessel was at full power on a production line. At 15:40 UTC the whale entered the EZ of 1500 meters to the active source and a shutdown was called for and immediately implemented. The whales CPA to the vessel was at this same time of 15:40 UTC at 1280 meters. The CPA to the source of 1200 meters was at 15:43 UTC. At 15:46 UTC the whale was observed at 1700 meters from the non-active source and the vessel's navigation was informed that the whale had left the EZ. The last sighting of the whale was when it was still blowing at 15:48 UTC and then lost in the severe glare. No VSA maneuvers were required or requested. See Figure 19 in Section 6.7.1.

VS #5: On 5 December 2024, at 16:20 UTC, a pod of 11 short-finned pilot whales were sighted 300 meters off the port bow with a true bearing of 170 degrees. The pod was initially crossing ahead of the vessel but was observed to turn to the north in an opposite but parallel direction as the vessel at 16:21 UTC. The vessel was at full power on a survey line at the time of initial sighting. When the pod entered the EZ of 500 meters to the active source a shutdown was called for and executed. The pod's CPA to the vessel maintained 300 meters through the sighting. The CPA to the source was 270 meters at 16:24 UTC. The pod dove not to be seen again at the same time of 16:24 UTC when the whales were in line with the stern off the port side of the vessel. The pod contained one juvenile pilot whale. No VSA request was made as the pod did not enter the separation distance of 50 meters. See Figure 20 in Section 6.7.1.

VS #6: On 13 December 2024, at 12:53 UTC, while the source was silent, an unidentified dolphin was sighted 13 meters off the forward of the port beam at a bearing of 290 degrees and heading of 210 degrees. The CPA the dolphin made to the vessel was 13 meters. The dolphin was 400 meters from the silent source. The dolphin surfaced briefly. The dolphin was last seen at 12:53 UTC, 13 meters off the forward of the port beam, 400 meters from the silent source, at a bearing of 290 degrees, and heading of 210 degrees. The closest approach the dolphin made to the silent source was 400 meters at 12:53 UTC. The dolphin was observed within the buffer zone of 1000 meters and not seen to leave the buffer zone. No mitigation downtime was required as no planned source activity was requested during the post silent time of the sighting. The implemented VSA mitigation of the vessel was to maintain course and speed since the gear was being towed at the time of the sighting. This sighting correlated with acoustic detection number 509 who detected the dolphin first.

VS #7: On 26 December 2024, at 16:56 UTC, one leatherback sea turtle was sighted 20 meters from the vessel's port bow, 380 meters from the sound source, at a bearing of 65 degrees with a heading of 81 degrees. The leatherback was below the surface swimming in the opposite direction of the vessel parallel to the vessel. At the time of sighting, the sound source was inactive. The vessel was in line change. The turtle surfaced 75 meters from the vessel's port

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side midship 295 meters from the inactive source, then again 75 meters from the inactive sound source. The animal dove at 16:58 and was not sighted again. CPA to the vessel was 20 meters. CPA to the inactive source was 75 meters. The vessel was in a line change which was extended by seven minutes so a full 30-minute pre-clearance could be completed. One mitigation action was required with a delay to soft start so pre-clearance could be completed. Vessel strike avoidance maneuvers were not required.

VS #8: On 20 January 2025, at 13:18 UTC, two unidentified dolphins were sighted 10 meters from the vessel's starboard bow, 380 meters from the sound source, at a bearing of 68 degrees with a heading of 58 degrees. The dolphins approached the vessel's bow porpoising twice. At the time of the sighting, the sound source was inactive as the vessel was in transit to port. Two dolphins were sighted only once with a CPA of 10 meters. There was a second sighting at 13:21 of a single dolphin five meters off the vessel's starboard side bow porpoising once. The dolphins were not seen again. They were likely bottlenose dolphins, but they could not be positively identified. CPA to the inactive source was 390 meters. No mitigation actions of VSA were required.

VS #9 Bottlenose Dolphin
On 21 January 2025, at 12:49 UTC, two bottlenose dolphins were sighted 50 meters from the vessel's port side stern at a bearing of 300 degrees with a heading of 278 degrees. The dolphins were milling at the surface. At the time of the sighting, the sound source was inactive as the vessel was in transit to port. Two dolphins were sighted only once with a CPA of 50 meters. CPA to the inactive source was 380 meters. No mitigation actions of VSA were required.

VS #10 Bottlenose Dolphin
On 21 January 2025, at 13:41 UTC, seven bottlenose dolphins were sighted 15 meters from the vessel's port side bow at a bearing of 305 degrees with a heading of 315 degrees. The dolphins were slowly transiting parallel to the vessel in the opposite direction. At the time of sighting, the sound source was inactive as the vessel was in transit to port. There were two small pods of dolphins totaling an estimated seven adults. They were sighted only once with a CPA of 15 meters to the vessel. CPA to the inactive source was 395 meters. No mitigation actions of VSA were required.

VS #11 Bottlenose Dolphin
On 21 January 2025, at 14:09 UTC, eight bottlenose dolphins were sighted 40 meters from the vessel's port side stern at a bearing of 345 degrees with a heading of 350 degrees. The dolphins were quickly transiting parallel to the vessel in the same direction as the vessel. At the time of detection, the sound source was inactive as the vessel was in transit to port. Eight dolphins were sighted only once with a CPA of 40 meters. CPA to the inactive source was 410 meters. No mitigation actions of VSA were required.

Please refer to Error! Reference source not found. as well as Error! Reference source not found. for further details on visual sightings.

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Table 8: Visual Sighting Data

Sighting No.	Date	Common Name	Species	Range of animal(s) when first detected (m)	Total group size	Source activity when animal first sighted	Source activity when animal last sighted	Closest distance of animals from source	What action was taken	Mitigation down time	Comments
1	11/5/2024	Common bottlenose dolphin	*Tursiops truncatus*	40	11	Silent	Silent	250	None	00:00	
2	11/22/2024	Unidentified turtle	--	5	1	Silent	Silent	300	Delay	30:00	Delay to start of ramp-up
3	11/27/2024	Sperm whale	*Physeter macrocephalus*	2500	1	Full Volume	Full Volume	2850	None	00:00	
4	11/27/2024	Sperm whale	*Physeter macrocephalus*	1700	1	Full Volume	Silent	1200	Shutdown	00:06	Whale was observed leaving EZ
5	12/5/2024	Short-finned pilot whale	*Globicephala macrorhynchus*	300	11	Full Volume	Silent	254	Shutdown	00:33	
6	12/13/2024	Unidentified dolphin	--	13	1	Silent	Silent	400	None	00:00	Correlated with AD 509
7	12/26/2024	Leatherback sea turtle	*Dermochelys coriacea*	20	1	Silent	Silent	75	Delay	00:07	Delay to start of ramp-up
8	1/20/2025	Unidentified *Delphinidae*	--	10	3	Silent	Silent	390	None	00:00	
9	1/21/2025	Common bottlenose dolphin	*Tursiops truncatus*	50	2	Silent	Silent	380	None	00:00	
10	1/21/2025	Common bottlenose dolphin	*Tursiops truncatus*	15	7	Silent	Silent	395	None	00:00	
11	1/21/2025	Common bottlenose dolphin	*Tursiops truncatus*	40	8	Silent	Silent	410	None	00:00	

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6.4. Descriptions of Protected Species Encountered

6.4.1. Rice´s Whale

In accordance with the new language in the BOEM permit, operators or their recognized representatives must notify BOEM or BSEE as appropriate of their intention to transit through the Rice's Whale Area (100-to-400-meter isobaths from 87.5° W to 27.5° N, as described in the species' status review plus an additional 10 km around that area) as shown in Figure 15 below.

For this survey the Rice's Whale Area should not be a consideration as the survey area and transit path in and out of the survey area does not approach the Rice's Whale Area.

There were no Rice's whale encounters, therefore there was no need to make any special report to BOEM or BSEE when transiting through the Rice's Whale Area.

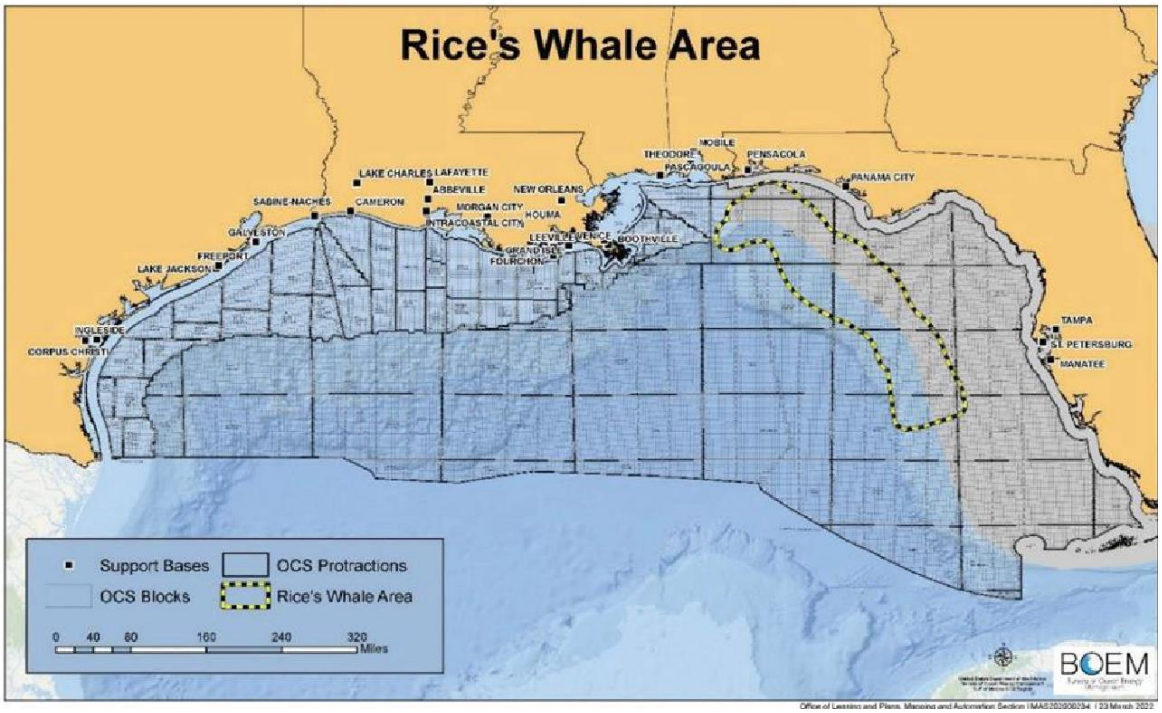

Figure 15: Rice's whale area as described in Permit L24-011

6.4.2. Sperm Whale

Sperm whales are the most common large whales found throughout the northern GOM, primarily at the continental shelf and slope, in waters deeper than 200 m, and along the 1000 m isobaths. Sperm whales are likely to travel in response to geographical and temporal variations in the abundance of medium- and large-sized pelagic squids, their primary prey. Species traits: Huge and squared head with narrow underslung lower jaw. Large and triangular flukes with smooth edges and deep notch. Dark gray-brown color with some lighter blotches and scarring around head. Single, smooth low dorsal hump, and distinctive 45 degrees blow can be observed.

6.4.3. Common bottlenose dolphin

Common bottlenose dolphins are found throughout the world in both offshore and coastal waters, including harbors, bays, gulfs, and estuaries of temperate and tropical waters. They get their name from their short, thick snout (or rostrum). They are generally gray in color. They can range from light gray to almost black on top near their dorsal fin and light gray to almost white on their belly. Bottlenose dolphins living in nearshore coastal waters are often smaller and lighter in color than those living offshore.

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6.4.4. Short-finned Pilot whale

Short-finned pilot whales are found globally in tropical and temperate oceans. They have a bulbous melon head with no obvious rostrum. Its dorsal fin is far forward on its body and has a relatively long base. The body is black or dark brown, with a large gray saddle behind the dorsal fin.

6.4.5. Leatherback Sea turtle

Leatherbacks occur in the Atlantic, Pacific, and Indian Oceans. The leatherback has a primarily black, rubbery skin with pinkish-white coloring on its underside. They are the only species of sea turtles that lack scales. Their shell (carapace) consists of small, interlocking dermal bones beneath the skin that overlie a supportive layer of connective tissue and fat and the deeper skeleton. Their carapace has seven ridges along its length and tapers to a blunt point.

6.5. PAM Summary

6.5.1. PAM Methods

PAM is designed to detect most species of marine mammals and was installed on the R/V Artemis Athene. PAM was conducted with a system provided by Seiche, comprising a 250-meter array cable with six hydrophones, a deck cable, an audio processing unit, and a computer. PAMGuard software was used for monitoring and detecting marine mammals when the array cable was deployed. A main system and a full spare were provided for full redundancy. The hydrophone cable included two low frequency (LF) hydrophones (10Hz to 24kHz), two ultra-broadband hydrophones (200Hz to 200kHz), and two broadband hydrophones (2kHz to 200kHz). The six hydrophones are arranged in three pairs of identical specifications with appropriate physical separation to provide direction-finding and localization.

Four PAM operators maintained a continuous watch for 24 hours whenever source operations were planned or being conducted, except during brief moments when malfunction was being resolved.

The 6-channel hydrophone array allows PAMs to view displays of processed and analyzed sound signals in two designations, by grouping the hydrophones into pairs for low, mid (MF), and high frequency (HF) analyzation (Figure 16). Four hydrophones are utilized for low-mid frequency analyzation target a frequency range between 0.2 kHz and ~24-48 kHz, targeting broad frequency sperm whale clicks and delphinid calls. The hydrophones used for high frequency analyzation target a frequency range of 2-200 kHz and are processed by the National Instruments USB 6251 DAQ, before being displayed on two scrolling click detector displays. Click detector shows two scrolling time displays, one with a scale for bearing and the other a scale for amplitude, and targets HF echolocation clicks of delphinid species and clicks of beaked whales. PAMGuard software can localize, or approximate distance of HF clicks, and LF and MF signals on a map display, with buffer and exclusion zone overlays relative to the source.

Raw feed from the two designated HF hydrophone elements was digitized in the buffer unit using an analog-digital National Instruments data acquisition (DAQ) soundcard at a sampling rate of 500 kHz. The output was filtered for HF content and visualized using the PAMGuard software. A scrolling bearing/time module displayed the filtered data in real time, allowing for the detection and directional mapping of click trains. Additional components of the HF click detector system in PAMGuard were an amplitude/time display that registered click intensity data in real time, as well as click waveform, click spectrum, and Wigner plot displays, providing the PAM Operator immediate review of individual click characteristics in the identification process.

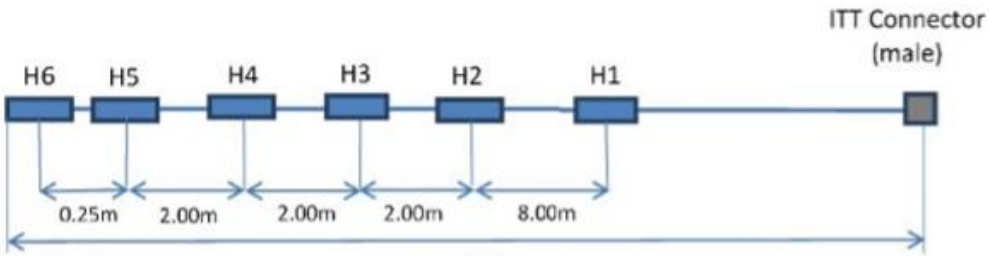

Figure 16: Schematic diagram of the hydrophone array cable indicating the position and separation of individual hydrophone elements and hydrophone pairs

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6.5.2. PAM Setup

The PAM monitoring station was set up in the instrument room (Figure 17). Both the main and the spare deck leads were both routed under the floor of the instrument room and server room and out the aft wall of the server room. The cables were then routed along the cable trays to the stern of the streamer deck where the hydrophone cables were set up on winches. At the stern of the streamer deck, both sets of tow and hydrophone cables were spooled onto mechanical winches on the port and starboard sides for quick deployment and retrieval. Throughout the survey both the port and starboard cables were used depending on the needs of the seismic crew.

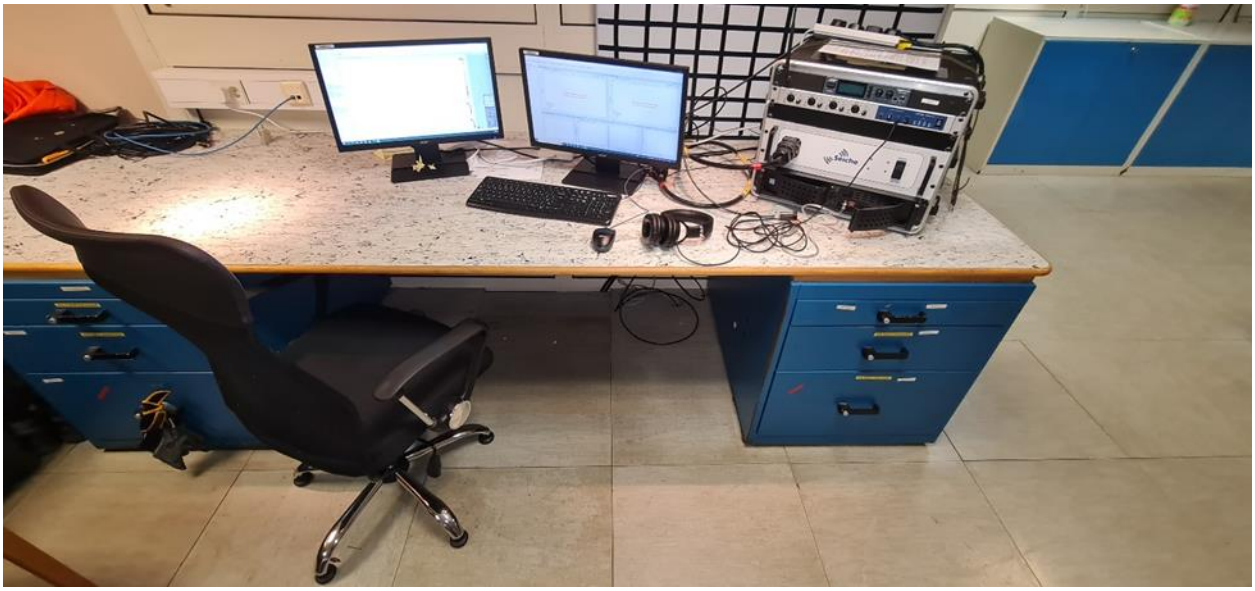

Figure 17: PAM monitoring station in instrument room

The PAM cable was deployed directly off the stern of the vessel from the streamer deck (Figure 18). When deploying, the 25 meters of hydrophone cable were deployed off the stern by hand. The source mechanic then opened the local hydraulic valves to activate and run the winch to deploy the cable to the desired tow length, which for the project was 145 meters of tow cable added to the 25-meter length of hydrophone cable.

Figure 18: PAM cable deployed off stern

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6.5.3. PAM Detections

During this project, the PAM team conducted a total of 1442 hours and 58 minutes of acoustic monitoring and recorded the following 15 acoustic detections.

AD 501: On 04 November 2024, at 01:40 UTC, scattered clicks from an unidentified delphinid were detected on PAMGuard's HF click detector. The signal was initially detected between the bearings of 0 and 105 degrees relative to the hydrophone array at 110 to 142 dB. Scattered clicks and click trains were seen until 01:45 UTC between the bearings of 15 and 130 degrees. Maximum amplitude of 142 dB was detected at 01:45 UTC, which may indicate the time of closest approach to the hydrophones. PAMGuard data indicated the presence of three animals within the 1000 meters buffer zone. When sound files were analyzed using Raven Lite, high frequency echolocation clicks were seen ranging from 15 to 130 kHz. At the time of the detection, the vessel was on standby, and the source was silent while the PAM operator completed the one-hour post operation watch. No mitigation actions were required.

AD 502: On 23 November 2024, at 03:35 UTC, scattered clicks and train clicks from an unidentified delphinid were detected on PAMGuard's HF click detector. The signal was initially detected between the bearings of 82 and 90 degrees relative to the hydrophone array, with an amplitude ranging between 122 to 124 dB. Scattered clicks and click trains were seen until 03:43 UTC between the bearings of 24 and 125 degrees throughout the event. Maximum amplitude of 135 dB was detected at 03:36 UTC, which may indicate the time of closest approach to the hydrophones. When sound files were analyzed using Raven Lite, high frequency echolocation clicks were seen ranging from 8 to 80 kHz. PAMGuard and Spectrogram data indicated the presence of at least 2 individuals within the 500 meters exclusion zone. A shut down mitigation action was called at 03:36 UTC as the vessel was with a soft start in progress. The shutdown of the source resulted in 38 minutes of mitigation downtime. See Figure 22 in Section 6.7.2.

AD 503: On 25 November 2024, at 07:55 UTC, dispersed clicks from unidentified delphinids were detected on PAMGuard's HF click detector. The signal was initially detected between the bearings of 20 and 125 degrees relative to the hydrophone array at amplitude of 125 to 135 dB. Scattered clicks and click trains were seen until 08:01 UTC between the bearings of 0 and 180 degrees. A maximum amplitude of 150 dB was detected at 08:00 UTC, which may indicate the time of closest approach to the hydrophones. When data from this time frame was analyzed using Target Motion Analysis, clicks were tracked to a distance of 31 meters from the hydrophone array and 200 meters from the acoustic source. When sound files were analyzed using Raven Lite, HF echolocation clicks were seen ranging from 20 to 210 kHz and a faint whistle was seen between 13 and 18 kHz. Five burst pulses were observed between 07:56 UTC and 07:58 UTC with a range between 30-90 kHz. PAMGuard and spectrogram data indicated the presence of at least three individuals within the 1000-meter BZ. At the time of the detection the source was being retrieved due to maintenance; therefore, no mitigation was required.

AD 504: On 28 November 2024, at 03:06 UTC, clicks from unidentified delphinids were detected on PAMGuard's MF spectrogram. At 03:08 UTC, scattered clicks and clicks trains were detected on PAMGuard's HF click detector. The signal was initially detected between the bearings of 24 and 45 degrees relative to the hydrophone array, with an amplitude ranging between 123 to 116 dB. Scattered clicks and click trains were observed until 04:42 UTC between the bearings of 0 and 169 degrees throughout the event. The maximum amplitude of 134 dB was detected at 03:11 UTC, which may indicate the time of closest approach to the hydrophones. When sound files were analyzed using Raven Lite, HF echolocation clicks were seen ranging from 8 to 237 kHz. Whistles were observed ranging from 19 to 35 kHz, with harmonics visible up to 45 kHz. PAMGuard's spectrogram data indicated the presence of at least six individuals within the 1000-meter BZ. No mitigation actions were implemented because, at the time of detection, the source was silent, and string two was recovered due to maintenance.

AD 505: On 01 December 2024, at 00:31 UTC, scattered and bunched clicks were observed on PAMGuard's HF click detector between the bearings of 120 to 55 degrees relative to the hydrophone array, with an amplitude between 115 to 150 dB. The source was active at reduced volume during a soft start and a shutdown was requested and immediately implemented by the seismic crew. Over the next nine minutes, frequent bunched and scattered clicks as well as small click trains were observed on the HF click detector. The clicks achieved a maximum amplitude of just under 160 dB. This amplitude was achieved throughout the detection. Additionally, whistles were briefly observed on the MF spectrogram at a frequency in the 5-10 kHz range, with harmonics at 15, 25, and 35 kHz. Clicks were last observed on the bearing time display at 00:40. When sound files were analyzed using Raven Lite, HF echolocation clicks were seen ranging from 10 to 210 kHz. The shutdown of the source resulted in 39 minutes of mitigation downtime. See Figure 23 in Section 6.7.2.

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AD 506: On 01 December 2024, at 01:21 UTC, whistles were observed on PAMGuard's MF spectrogram just prior to soft start. Over the next 54 minutes, clicks and click trains were observed on the HF click detector at amplitude range of 110-140 dB. As a result, the vessel aborted approach to soft start and circled until given the all-clear to begin another approach. The animals were last detected at 02:15 UTC. Analysis on Raven Lite showed the whistles to range from 11 to 50 kHz with a primary frequency of 38.6 kHz. A delay to the initiation of the source resulted in 1 hour and 26 minutes of mitigation downtime. See Figure 24 in Section 6.7.2.

AD 507: On 01 December 2024, at 07:01 UTC, scattered clicks and click trains were detected on PAMGuard's HF click detector. Clicks were initially detected between the bearings of 100 to 140 degrees relative to the hydrophone array between amplitude 120 to 30 dB. The last detection occurred at 07:04 UTC. Overall, the detection lasted three minutes. Click bearings ranged overall 180 degrees relative to the hydrophones and ranged from 110 to 150 dB. The maximum amplitude was 160 dB which occurred at 07:02 UTC, suggesting this was the closest approach to the hydrophones. Sound files were analyzed with Raven Lite, and results showed clicks in the 10 to 230 kHz range. Two burst pulses were observed at 07:01 UTC with a range between 10-140 dB and 10-200 dB. PAMGuard and spectrogram data indicated the presence of one individual within the 500-meter BZ. During the detection the vessel was on a production line and the source was active at full volume. No mitigation actions were implemented due to shutdowns being waived for acoustic only detections of delphinids.

AD 508: On 06 December 2024, at 09:43 UTC, two click trains were observed on PAMGuard's HF click detector. Clicks were initially detected between the bearings of 10 to 150 degrees relative to the hydrophone array between amplitude 110 to 140 dB. The last detection occurred at 09:45 UTC. Sound files were analyzed with Raven Lite, and results showed clicks in the 40 to 180 kHz range. PAMGuard and spectrogram data indicated the presence of two individuals within the 1000-meter BZ. During the detection the vessel was on a line change and the sound source was silent. No mitigation actions were necessary as the animals were last detected more than 30 minutes prior to the planned commencement of soft start.

AD 509: On 13 December 2024, at 12:47 UTC, several faint whistles were detected aurally, though they did not appear on the spectrogram display. No click trains were visible during this period, and no further acoustic detections were recorded after 12:47 UTC. At 12:53 UTC, PSOs identified a single, unidentified dolphin, with visual data documented in VD 6. Analysis of the sound files using Raven Lite revealed whistles at a frequency of 11 kHz. Although clicks were not detected by the HF click detection module of PAMGuard, short click trains were observed in Raven Lite, ranging from 10 to 90 kHz with an inter-click interval (ICI) of 0.02 to 0.05 seconds. During this detection period, the vessel was operating on a production line with the source active at full volume. No mitigation actions were implemented, as shutdowns were waived for acoustic-only detections of delphinids.

AD 510: On 28 December 2024, at 01:55 UTC, several faint whistles were detected aurally by the PAM operator and seen on PAMGuard's MF spectrogram display. No click trains were visible during this period, and the last whistles were seen at 01:58 UTC. Analysis of the sound files using Raven Lite revealed whistles between 7 and 17 kHz with harmonics visible up to 40 kHz. Although clicks were not detected by the HF click detection module of PAMGuard, short click trains were observed in Raven Lite, ranging from 20 to 215 kHz. During this detection period, the vessel was operating on a production line with the source active at full volume. No mitigation actions were implemented, as shutdowns were waived for acoustic-only detections of delphinids.

AD 511: On 29 December 2024, at 01:27 UTC, click trains from an unidentified delphinid were detected on PAMGuard's HF click detector. The signal was initially detected between the bearings of 60 to 100 degrees relative to the hydrophone array at amplitude 123 to 130 dB. Scattered clicks and click trains were seen until 03:05 UTC between a bearing of 0 to 180 degrees. Maximum amplitude of 165 dB was detected at 01:29 UTC, which may indicate the time of closest approach to the hydrophones. When sound files were analyzed using Raven Lite, HF echolocation clicks were seen ranging from 10 to 250 kHz mainly between 30 and 200 kHz. In addition, HF burst pulses were detected between 20 and 200 kHz and LF whistles were seen between 7 and 22 kHz with harmonics up to 30 kHz. PAMGuard and spectrogram data indicated the presence of at least five individuals within the 1000-meter BZ. At the time of detection, the vessel was on a line change and the source was silent preparing for a soft start. A delay to the initiation of the source was implemented and resulted in two hours and eight minutes of mitigation downtime. See Figure 25 in Section 6.7.2.

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AD 512: On 29 December 2024, at 10:32 UTC, clicks and whistles were detected on PAMGuard's MF Spectrogram and HF click detector display. Several click trains were visible during this period, and the last detection of clicks were seen at 10:37 UTC with closest approach occurring at 10:33 UTC. This indicated the presence of approximately four individuals. Analysis of the sound files using Raven Lite revealed up-sweep, down-sweep, and sinusoidal whistles between 7 and 22 kHz. Burst pulses were also detected during this analysis from 21-104 kHz. Clicks and click trains were detected by the HF click detection module of PAMGuard from 123-161 dB at bearings ranging from 0-180 degrees. Click trains were observed in Raven Lite, ranging from 7 to 250 kHz. At the time of detection, the vessel was on line change and the source was silent preparing for a soft start. A delay to the initiation of the source was implemented and resulted in 35 minutes of mitigation downtime. See Figure 26 in Section 6.7.2.

AD 513: On 31 December 2024, at 00:29 UTC, a click train from an unidentified delphinid was detected on PAMGuard's HF click detector. The signal was initially detected between the bearings of 30 and 62 degrees relative to the hydrophone array at amplitude 121 to 136 dB. Scattered clicks and click trains were seen until 00:32 UTC between the bearings of 30 and 165 degrees. Maximum amplitude 136 dB was detected at 00:30 UTC, which may indicate the time of closest approach to the hydrophones. PAMGuard and spectrogram data indicated the presence of at least two animals within the 1000-meter BZ. When sound files were analyzed using Raven Lite, HF echolocation clicks were seen ranging from 15 to 135 kHz, whistles were seen ranging from 10 to 20 kHz with harmonics visible up to 80 kHz. At the time of the detection, the vessel was on a line change and the source was silent. No mitigation actions were implemented due to the extended time needed to reach the next line.

AD 514: On 2 January 2025, at 01:22 UTC, scattered clicks from an unidentified delphinid was detected on PAMGuard's HF click detector. The signal was initially detected between the bearings of 60 and 100 degrees relative to the hydrophone array at amplitude 121 to 134 dB. Scattered clicks and click trains were seen until 01:35 UTC between the bearings of 0 and 180 degrees. Maximum amplitude 147 dB was detected at 1:26 UTC, which may indicate the time of closest approach to the hydrophones. PAMGuard and spectrogram data indicated the presence of at least three animals within the 1000-meter BZ. When sound files were analyzed using Raven Lite, HF echolocation clicks were seen ranging from 20 to 210 kHz, and HF burst pulses were seen ranging from 15 to 160 kHz. At the time of the detection, the vessel was on a line change and the source was silent. Ramp up was scheduled for 01:50 UTC and a delay to the initiation of the source resulted in 15 minutes of mitigation downtime. See Figure 27 in Section 6.7.2.

AD 515: On 08 January 2025, at 10:11 UTC, a single click train was detected on PAMGuard's HF click detector display. This single click train was the only one visible during this period, and the last detection of clicks was seen at 10:12 UTC with closest approach occurring at 10:11 UTC. This indicated the presence of one individual within the 1000-meter BZ. Click train was detected by the HF click detection module of PAMGuard from 122 to 133 dB, at bearings ranging from 75-88 degrees. Analysis of the sound files using Raven Lite revealed click trains ranging from 7 to 173 kHz. At the time of detection, the vessel was on a line change and the source was silent preparing for a soft start. A delay to the initiation of the source was implemented and resulted in 31 minutes of mitigation downtime. See Figure 28 in Section 6.7.2.

Please refer to Table 9 and APPENDIX A for further details on acoustic detections.

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Table 9: Acoustic Detections Data

Detection No.	Date	Species	Range of animal(s) to vessel (m)	Total group size	Source activity when animal first sighted	Source activity when animal last sighted	Closest distance of animals from source	What action was taken	Mitigation down time	Comments
501	11/4/2024	Delphinidae	500	3	Silent	Silent	500	None	00:00	
502	11/23/2024	Delphinidae	500	2	Soft Start	Silent	500	Shutdown	00:38	Estimated production loss 00:46
503	11/25/2024	Delphinidae	200	3	Silent	Silent	200	None	00:00	
504	11/28/2024	Delphinidae	500	6	Silent	Silent	500	None	00:00	
505	12/1/2024	Delphinidae	500	3	Soft Start	Silent	400	Shutdown	00:39	Estimated production loss 00:59
506	12/1/2024	Delphinidae	500	5	Silent	Silent	500	Delay	01:24	Estimated production loss 01:24
507	12/1/2024	Delphinidae	500	1	Full Volume	Full Volume	500	None	00:00	
508	12/6/2024	Delphinidae	500	2	Silent	Silent	500	None	00:00	
509	12/13/2024	Delphinidae	500	1	Full Volume	Silent	500	None	00:00	Correlated with VD 6, Production line ended during detection.
510	12/28/2024	Delphinidae	500	1	Full Volume	Full Volume	500	None	00:00	
511	12/29/2024	Delphinidae	500	5	Silent	Silent	500	Delay	02:08	Estimated production loss 02:09
512	12/29/2024	Delphinidae	500	4	Silent	Silent	500	Delay	00:35	
513	12/31/2024	Delphinidae	500	2	Silent	Silent	500	None	00:00	
514	1/2/2025	Delphinidae	500	3	Silent	Silent	500	Delay	00:15	
515	1/8/2025	Delphinidae	500	1	Silent	Silent	500	Delay	00:31	Estimated production loss 00:36

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6.6. Other Wildlife

Throughout this reporting period, different species of fish and birds were observed. The only fish species present around the vessel were occasional flying fish species. Avian species present around the vessel have included Brown Booby (*Sula leucogaster*), Masked Booby (*Sula dactylatra*), Northern Gannet (*Morus bassanus*), Brown Pelican (*Pelecanus occidentalis*), Laughing Gull (*Leucophaeus atricilla*), and Magnificent Frigatebirds (*Fregata magnificens*).

Brown booby (Figure 19) were the most common avian species seen in the survey area and were observed nearly every day. All other avian sightings were infrequent.

Figure 19: Brown booby, Photo Credit: Samual Dorado

6.7. Mitigation Actions

During this survey there were 11 mitigation actions which totaled 8 hours and 45 minutes of mitigation downtime.

6.7.1. Visual Mitigations

A total of four visual sightings resulted in mitigation actions: two delays to the initiation of the source and two shutdowns of the source. In combination, visual sightings are attributed to two hours of mitigation downtime. The following visual sightings resulted in mitigation actions:

VD 02: On 22 November 2024, at 17:17 UTC, while the source was silent and the vessel was on a line change, an unidentified sea turtle was sighted five meters abaft of the starboard beam at a bearing of 110 degrees and heading of 25 degrees. The CPA to the vessel was five meters. The unidentified sea turtle was 300 meters from the silent source. The sea turtle surfaced, floated atop the water briefly, and then dove underneath. The sea turtle was last seen at 17:18 UTC five meters abaft of the starboard beam, 300 meters from the silent source, at a bearing of 110 degrees, and heading of 25 degrees. The closest approach the sea turtle made to the silent source was 300 meters at 17:17 UTC. The sea turtle was sighted within the buffer zone of 1000 meters during pre-clearance and not seen leaving the buffer zone, therefore a mitigation delay of 30 minutes was implemented before initiating soft start. The total mitigation down time was 30 minutes as the sighting occurred just as the PAM operator was about to call to initiate soft start.

VD 04: On 27 November 2024, at 15:38 UTC, a single sperm whale was sighted blowing 1700 meters off the vessel's beam on the starboard side (Figure 20). The whale was stationary. The whale was oriented to the east. At the time of the sighting the vessel was at full power on a production line. At 15:40 UTC the whale entered the EZ of 1500 meters to the active source and a shutdown was called for and immediately implemented. The whales CPA to the

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vessel was at this same time of 15:40 UTC at 1280 meters. The CPA to the source of 1200 meters was at 15:43 UTC. At 15:46 UTC the whale was observed at 1700 meters from the non-active source and the vessel's navigation was informed that the whale had left the EZ. The last sighting of the whale was when it was still blowing at 15:48 UTC and then lost in the severe glare. No VSA maneuvers were required or requested.

Figure 20: VD4 – Sperm whale blowing

VD 05: On 5 December 2024, at 16:20 UTC, a pod of 11 short-finned pilot whales were sighted 300 meters off the port bow with a true bearing of 170 degrees (Figure 21). The pod was initially crossing ahead of the vessel but was observed to turn to the north in an opposite but parallel direction as the vessel at 16:21 UTC. The vessel was at full power on a survey line at the time of initial sighting. When the pod entered the EZ of 500 meters to the active source a shutdown was called for and executed. The pod's CPA to the vessel maintained 300 meters through the sighting. The CPA to the source was 270 meters at 16:24 UTC. The pod dove not to be seen again at the same time of 16:24 UTC when the whales were in line with the stern off the port side of the vessel. The pod contained one juvenile pilot whale. No VSA request was made as the pod did not enter the separation distance of 50 meters.

Figure 21: VD5 – Pod of short-finned pilot whales

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VD 07: On 26 December 2024, at 16:56 UTC, one leatherback sea turtle was sighted 20 meters from the vessel's port bow, 380 meters from the sound source, at a bearing of 65 degrees with a heading of 81 degrees. The leatherback was below the surface swimming in the opposite direction of the vessel parallel to the vessel. At the time of sighting, the sound source was inactive. The vessel was in line change. The turtle surfaced 75 meters from the vessel's port side midship 295 meters from the inactive source, then again 75 meters from the inactive sound source. The animal dove at 16:58 and was not sighted again. CPA to the vessel was 20 meters. CPA to the inactive source was 75 meters. The vessel was in a line change which was extended by seven minutes so a full 30-minute pre-clearance could be completed. One mitigation action was required with a delay to soft start so pre-clearance could be completed. Vessel strike avoidance maneuvers were not required.

6.7.2. Acoustic Detections

A total of seven acoustic detections resulted in mitigation actions: five delays to the initiation of the source and two shutdowns of the source. In combination, acoustic detections are attributed to 6 hours and 45 minutes of mitigation downtime during this reporting period. The following acoustic detections resulted in mitigation actions:

AD 502: On 23 November 2024, at 03:35 UTC, scattered clicks and train clicks from an unidentified delphinid were detected on PAMGuard's HF click detector (Figure 22). The signal was initially detected between the bearings of 82 and 90 degrees relative to the hydrophone array, with an amplitude ranging between 122 to 124 dB. Scattered clicks and click trains were seen until 03:43 UTC between the bearings of 24 and 125 degrees throughout the event. Maximum amplitude of 135 dB was detected at 03:36 UTC, which may indicate the time of closest approach to the hydrophones. When sound files were analyzed using Raven Lite, high frequency echolocation clicks were seen ranging from 8 to 80 kHz. PAMGuard and Spectrogram data indicated the presence of at least 2 individuals within the 500 meters exclusion zone. A shut down mitigation action was called at 03:36 UTC as the vessel was with a soft start in progress. The shutdown of the source resulted in 38 minutes of mitigation downtime.

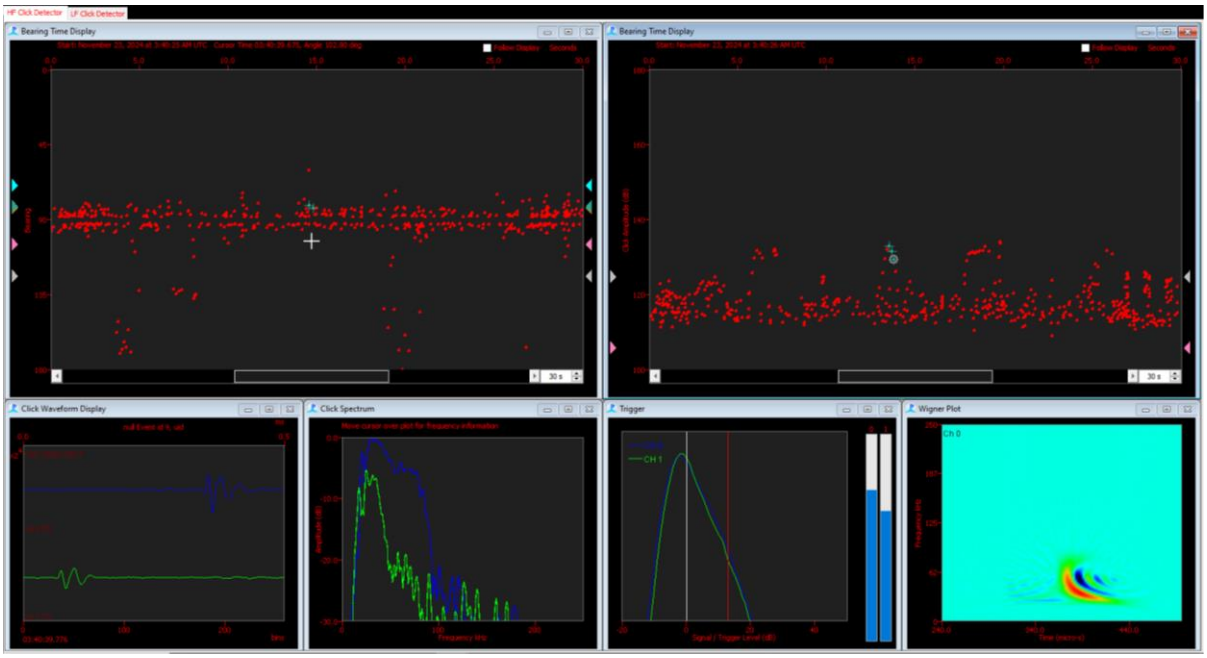

Figure 22: Scattered clicks and train clicks from an unidentified delphinid

AD 505: On 01 December 2024, at 00:31 UTC, scattered and bunched clicks were observed on PAMGuard's HF click detector between the bearings of 120 to 55 degrees relative to the hydrophone array, with an amplitude between 115 to 150 dB (Figure 23). The source was active at reduced volume during a soft start and a shutdown was requested and immediately implemented by the seismic crew. Over the next nine minutes, frequent bunched and scattered clicks as well as small click trains were observed on the HF click detector. The clicks achieved a maximum amplitude of just under 160 dB. This amplitude was achieved throughout the detection. Additionally, whistles were briefly observed on the MF spectrogram at a frequency in the 5-10 kHz range, with harmonics at 15, 25, and 35 kHz. Clicks were last observed on the bearing time display at 00:40. When sound files were analyzed using Raven Lite, HF echolocation clicks were seen ranging from 10 to 210 kHz. The shutdown of the source resulted in 39 minutes of mitigation downtime.

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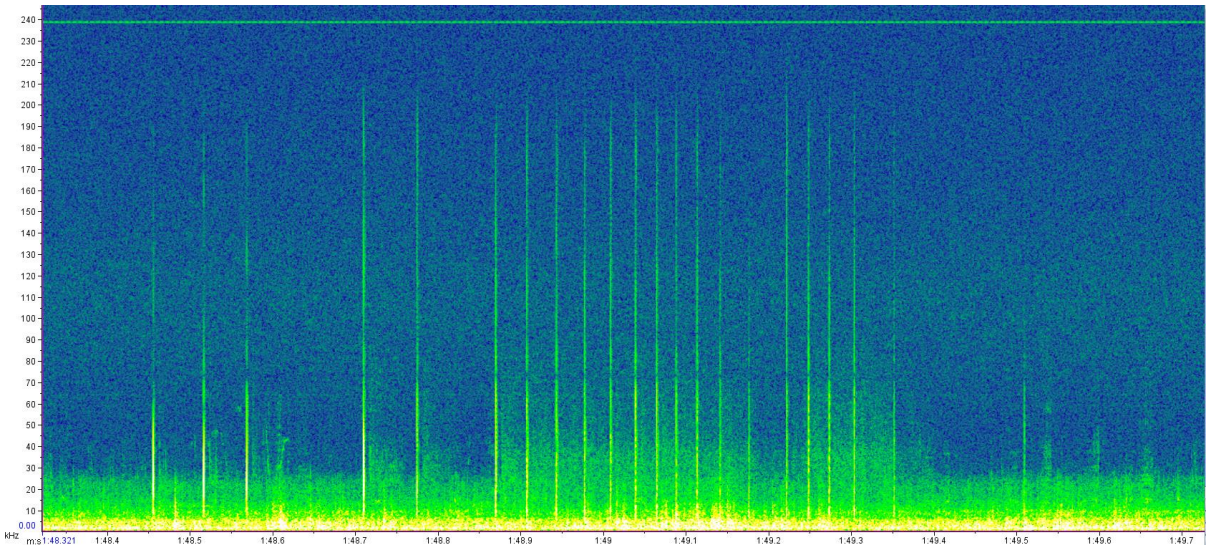

Figure 23: Scattered clicks and bunched clicks from an unidentified delphinid

AD 506: On 01 December 2024, at 01:21 UTC, whistles were observed on PAMGuard's MF spectrogram just prior to soft start (Figure 24). Over the next 54 minutes, clicks and click trains were observed on the HF click detector at amplitude range of 110-140 dB. As a result, the vessel aborted approach to soft start and circled until given the all-clear to begin another approach. The animals were last detected at 02:15 UTC. Analysis on Raven Lite showed the whistles to range from 11 to 50 kHz with a primary frequency of 38.6 kHz. A delay to the initiation of the source resulted in 1 hour and 26 minutes of mitigation downtime.

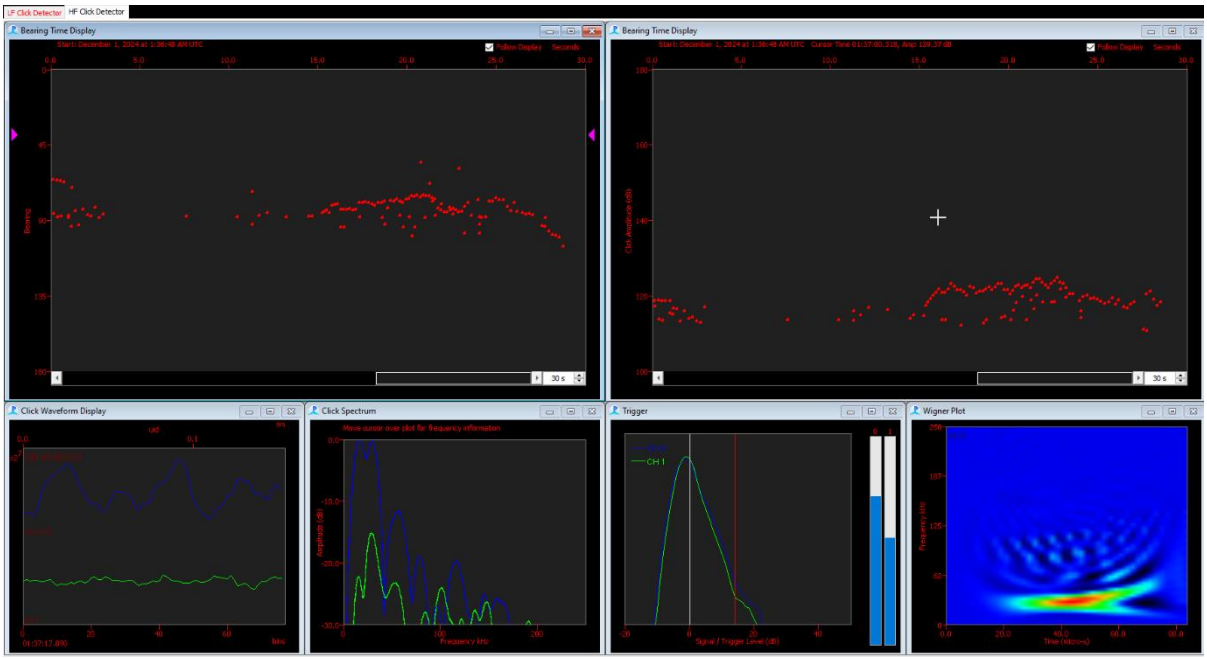

Figure 24: Whistles from unidentified delphinid

AD 511: On 29 December 2024, at 01:27 UTC, click trains from an unidentified delphinid were detected on PAMGuard's HF click detector (Figure 25). The signal was initially detected between the bearings of 60 to 100 degrees relative to the hydrophone array at amplitude 123 to 130 dB. Scattered clicks and click trains were seen until 03:05 UTC between a bearing of 0 to 180 degrees. Maximum amplitude of 165 dB was detected at 01:29 UTC, which may indicate the time of closest approach to the hydrophones. When sound files were analyzed using Raven Lite, HF echolocation clicks were seen ranging from 10 to 250 kHz mainly between 30 and 200 kHz. In addition, HF burst pulses were detected between 20 and 200 kHz and LF whistles were seen between 7 and 22 kHz with harmonics up to 30 kHz. PAMGuard and spectrogram data indicated the presence of at least five individuals within the 1000-meter BZ. At the time of detection, the vessel was on line change and the source was silent preparing for a

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soft start. A delay to the initiation of the source was implemented and resulted in two hours and eight minutes of mitigation downtime.

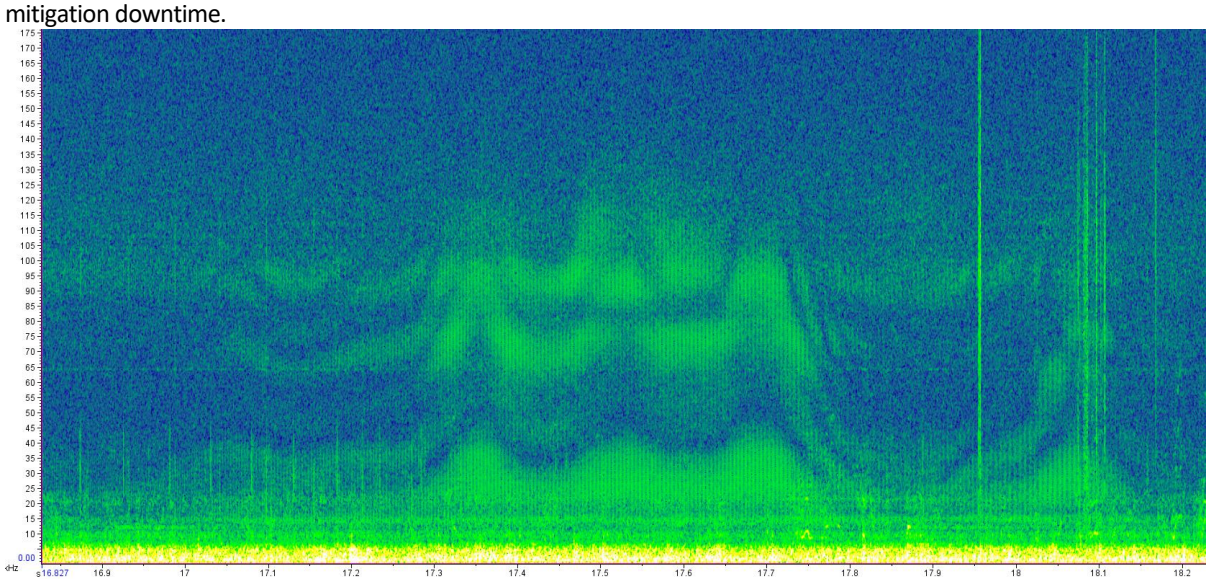

Figure 25: Click trains from an unidentified delphinid

AD 512: On 29 December 2024, at 10:32 UTC, clicks and whistles were detected on PAMGuard's MF Spectrogram and HF click detector display (Figure 26). Several click trains were visible during this period, and the last detection of clicks were seen at 10:37 UTC with closest approach occurring at 10:33 UTC. This indicated the presence of approximately four individuals. Analysis of the sound files using Raven Lite revealed up-sweep, down-sweep, and sinusoidal whistles between 7 and 22 kHz. Burst pulses were also detected during this analysis from 21-104 kHz. Clicks and click trains were detected by the HF click detection module of PAMGuard from 123-161 dB at bearings ranging from 0-180 degrees. Click trains were observed in Raven Lite, ranging from 7 to 250 kHz. At the time of detection, the vessel was on line change and the source was silent preparing for a soft start. A delay to the initiation of the source was implemented and resulted in 35 minutes of mitigation downtime.

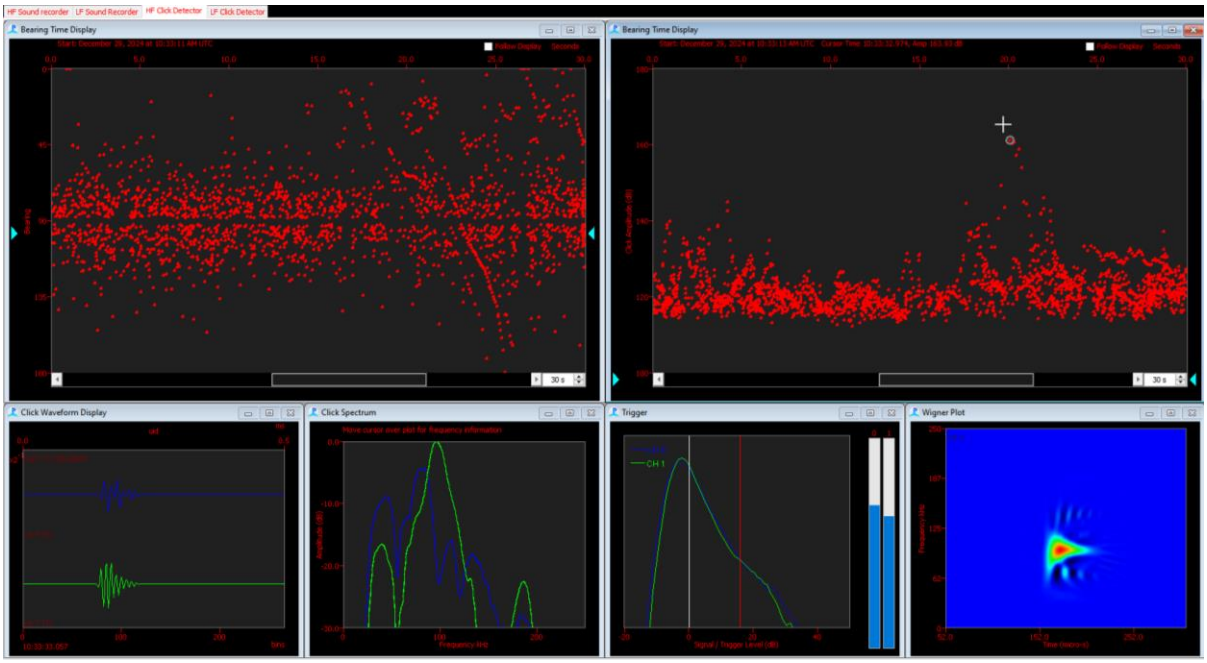

Figure 26: Click and whistles from an unidentified delphinid

AD 514: On 2 January 2025, at 01:22 UTC, scattered clicks from an unidentified delphinid was detected on PAMGuard's HF click detector (Figure 27). The signal was initially detected between the bearings of 60 and 100 degrees relative to the hydrophone array at amplitude 121 to 134 dB. Scattered clicks and click trains were seen until 01:35 UTC between the bearings of 0 and 180 degrees. Maximum amplitude 147 dB was detected at 1:26 UTC,

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which may indicate the time of closest approach to the hydrophones. PAMGuard and spectrogram data indicated the presence of at least three animals within the 1000-meter BZ. When sound files were analyzed using Raven Lite, HF echolocation clicks were seen ranging from 20 to 210 kHz, and HF burst pulses were seen ranging from 15 to 160 kHz. At the time of the detection, the vessel was on a line change and the source was silent. Ramp up was scheduled for 01:50 UTC and a delay to the initiation of the source resulted in 15 minutes of mitigation downtime.

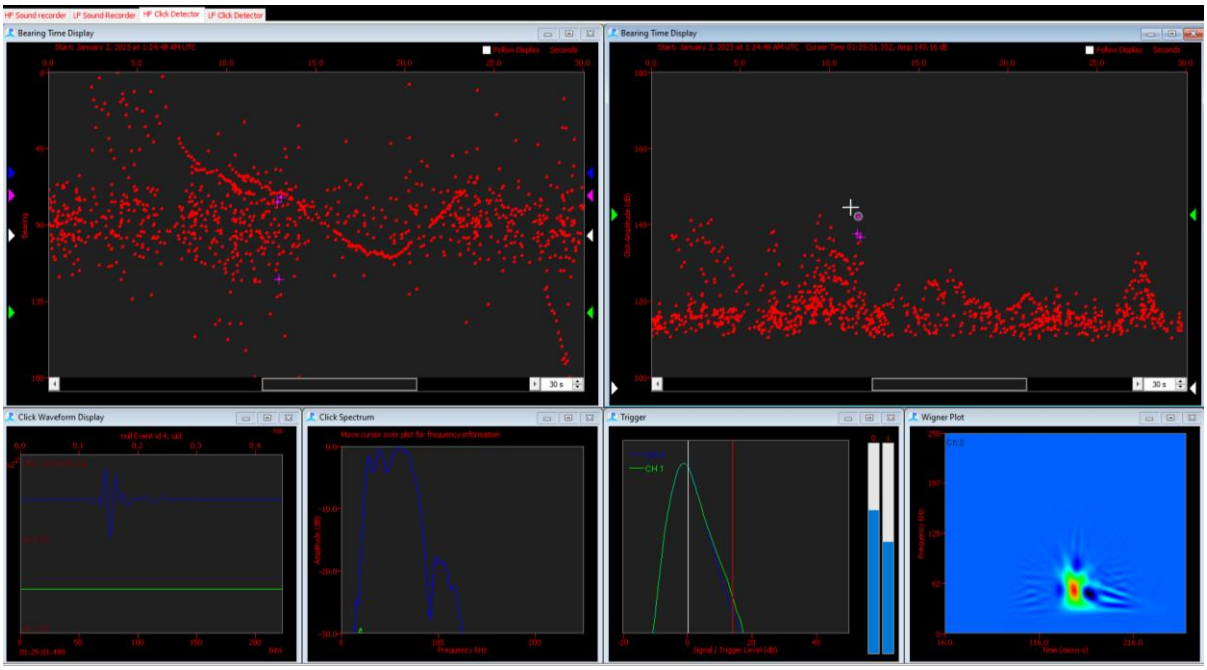

Figure 27: Scattered clicks from an unidentified delphinid

AD 515: On 08 January 2025, at 10:11 UTC, a single click train was detected on PAMGuard's HF click detector display (Figure 28). This single click train was the only one visible during this period, and the last detection of clicks was seen at 10:12 UTC with closest approach occurring at 10:11 UTC. This indicated the presence of one individual within the 1000-meter BZ. Click train was detected by the HF click detection module of PAMGuard from 122 to 133 dB, at bearings ranging from 75-88 degrees. Analysis of the sound files using Raven Lite revealed click trains ranging from 7 to 173 kHz. At the time of detection, the vessel was on a line change and the source was silent preparing for a soft start. A delay to the initiation of the source was implemented and resulted in 31 minutes of mitigation downtime.

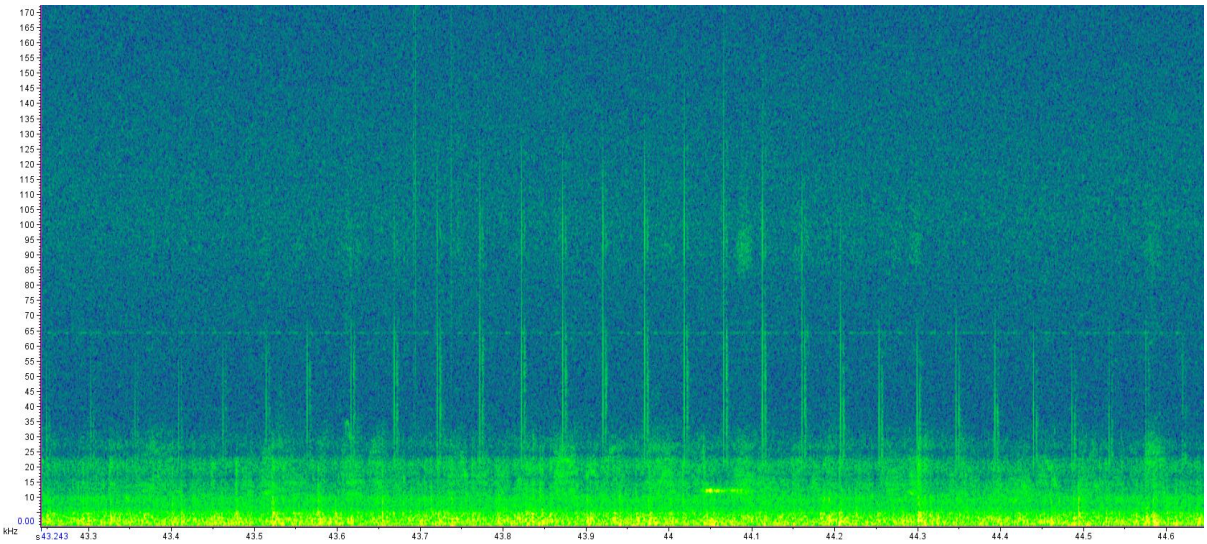

Figure 28: Single click train from an unidentified delphinid

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7.0 Weather

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7.1. Weather Conditions

During this survey, observation conditions were considered good to moderate. Choppy sea surface conditions (46.23%) were the most prevalent followed by slight (42.08%). Scattered light to medium rain showers occurred infrequently. During the transit to port on 21 January 2024, there was freezing rain and snow that reduced visibility significantly. Swells were typically between two and four meters with Beaufort of four being the most common. The maximum Beaufort was a seven. Wind speeds ranged from 2 to 40 knots. Visual distance (how far the PSO could see with the unaided eye) was greater than 5km for 85.40% of the monitoring effort. Reduced visibility occurred during periods of pre-sunrise, post-sunset, and during inclement weather. The weather conditions for this reporting period are shown below in Figure 29, 30, 31, 32 and 33.

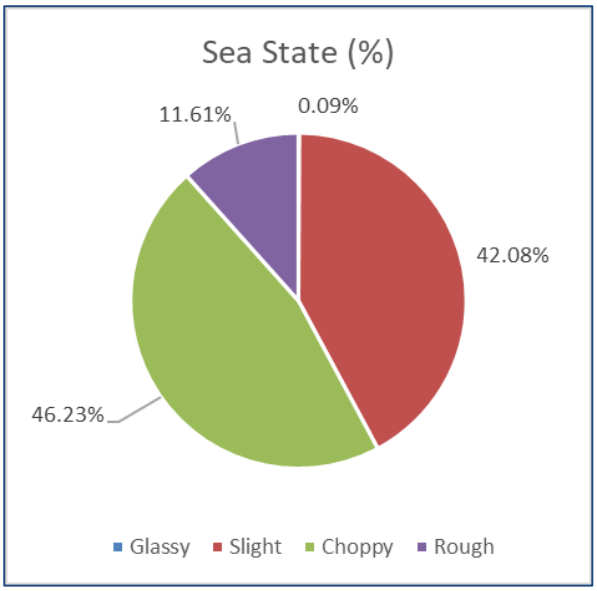

Figure 29: Percentages of Sea State

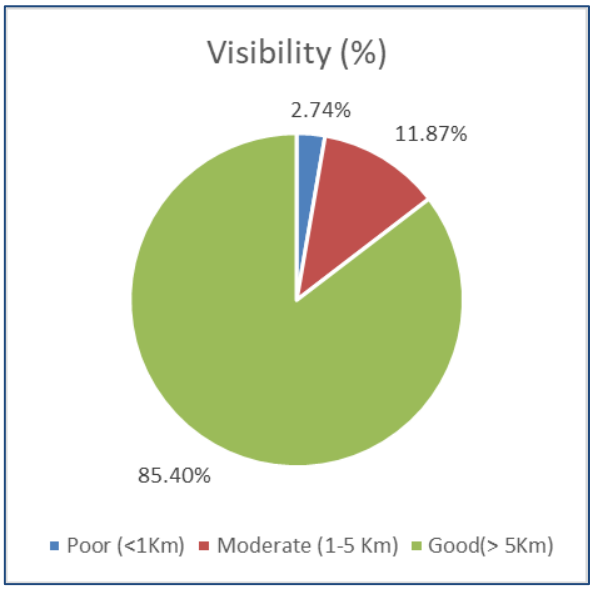

Figure 30: Percentages of Visibility

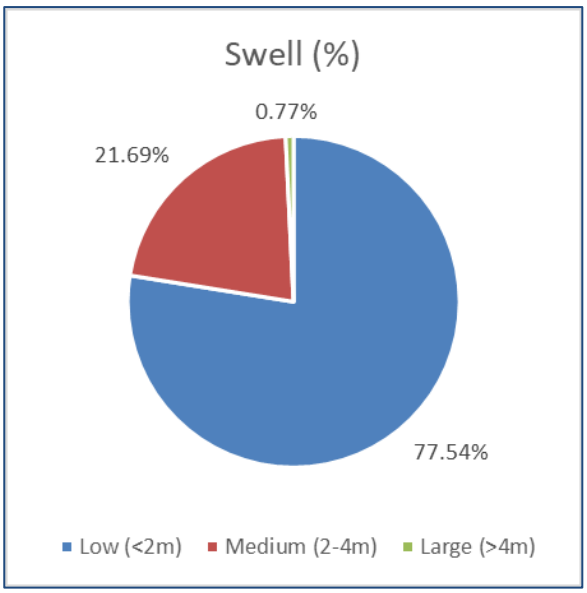

Figure 31: Percentages of Swell Height

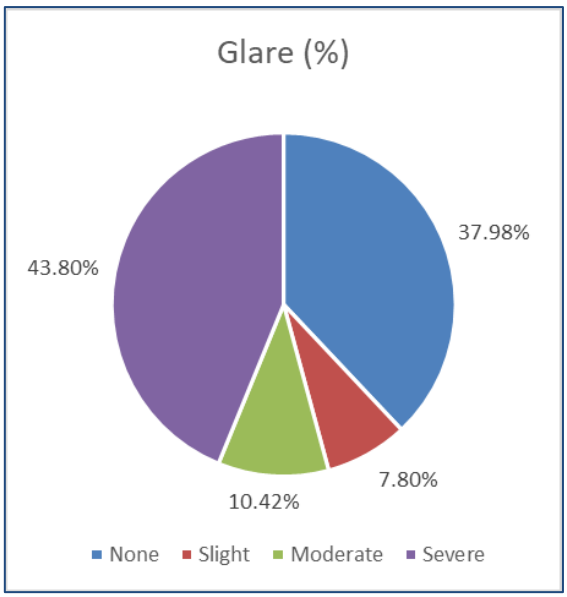

Figure 32: Percentages of Glare

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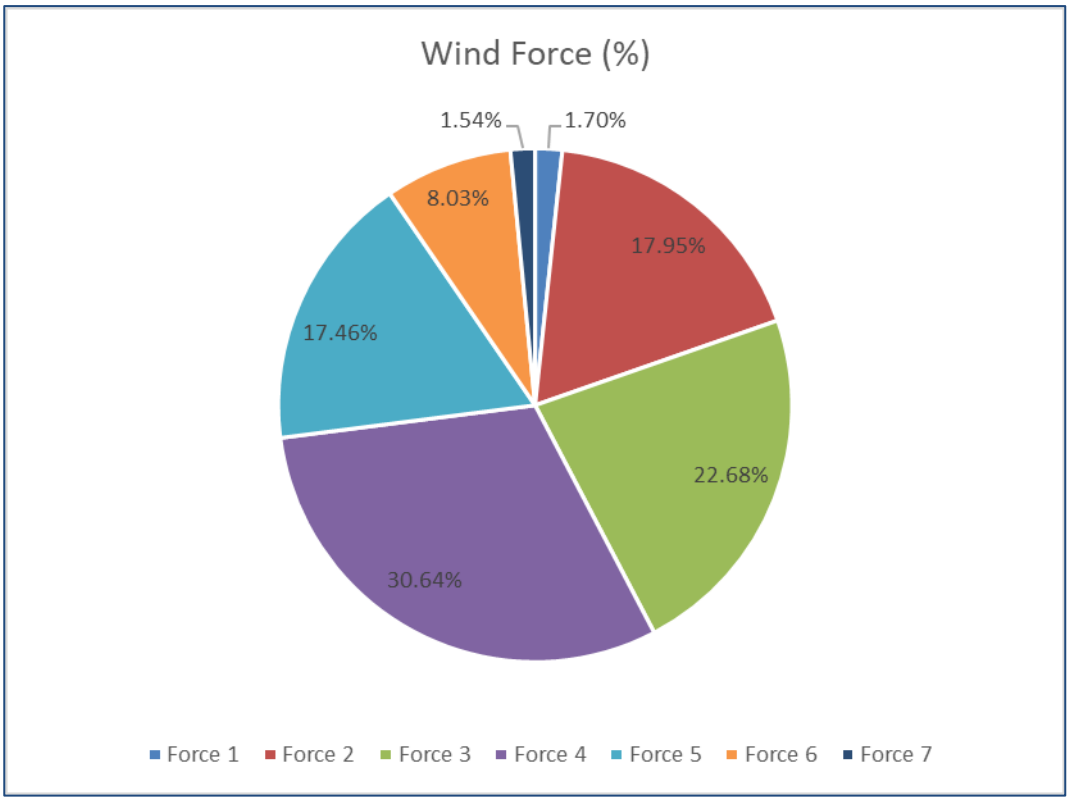

Figure 33: Percentages of Wind Force

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8.0 Conclusion

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8.1. Compliance with Guidelines

All seismic operations, including pre-watches and soft starts, complied fully with current BOEM / NMFS required guidelines, survey consent (permit) requirements, and the project recommendations. The survey was considered successful at minimizing the risk of disturbance and injury to marine mammals from the seismic survey.

There was no non-compliance events recorded.

- Marine mammal monitoring was undertaken by trained and experienced dedicated PSO's and PAM operators who did not have any other duties.
- There were no instances of vessel strikes with marine fauna.
- There were no observations of protected species becoming entangled as a result of the seismic operation.

8.2. Conclusions

The RV *Artemis Athene* began the survey for Green Canyon OBN for Murphy on 03 November 2024 with data acquisition beginning 12 November and completed data acquisition on 19 January 2025. There was a total of 84 survey days and a total of 69 data acquisition days (source was active). Of the 84 survey days, the vessel was at sea and visual monitoring was conducted for 81 days. The remaining days (3) were spent alongside in Gulfport, MS.

The Biological Opinion issued by NMFS on March 13, 2020, survey permit issued by BOEM (L23-033), LOA issued by NMFS, and project requirements were complied with. The seismic survey was successfully completed within the dates of its validity.

There were 11 mitigation actions which were necessary when marine mammals/sea turtles were observed/detected, totaling 8 hours and 45 minutes of mitigation downtime and zero non-compliance issues for the duration of the project. In total, there were 15 acoustic detections and 11 visual sightings

Weather conditions were for observing marine fauna were considered good to moderate throughout the survey. Reduced visibility occurred during periods of pre-sunrise, post-sunset, and during inclement weather.

There was full cooperation from the vessel personnel for the implementation of BOEM and NMFS Biological Opinion guidelines and all permit requirements. All pre-watches and soft starts were correctly executed.

There were no observations of injuries or mortalities to cetaceans, marine mammals, sea turtles, or seabirds

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9.0 Citations

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Appendices

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Appendix A PSO & PAM Data Forms

PSO & PAM monitoring effort, protected species detections, and source operations are included in Excel spread sheet attached with this report.

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Appendix B Report Certification

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Report Certification

In accordance with the Letter of Authorization issued for this project, this letter serves as certification that the Lead PSO and Lead PAM Operator confirm that the data collected by the offshore observers and information provided within the final report are accurate to the best of their knowledge.

	Lead PSO	Lead PAM Operator
Signature:	Rachel Rice Signer ID: TODOBHCIXO...	Sam Dorado Signer ID: OMM3BUT7KP...
Name:	Rachel Rice	Sam Dorado
Date:	04/08/2025 PDT	04/08/2025 PDT
Vessel:	Artemis Athene	Artemis Athene

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Appendix C PAM Calibration Validation

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SM.7955 System Frequency Response

This PAM system has been calibrated so that realistic sound level and signal amplitudes values may be displayed in PAM software. The system frequency response of the system when using this hydrophone array is shown below, and calibration settings are provided for use in Pamguard.

Table 2 provides -3 dB and -6 dB points of the system response curves for hydrophones in each group. These points delimit the 'flat' portion of the response curve. Groups H1-H2 and H3-H4 are acquired by the Fireface 800/802 sound card. Group H5-H6 is acquired by the NI USB-6251 DAQ. The frequency response curves are shown in Fig. 14.

Table 2 Frequency points for -3 dB and -6 dB sensitivity, for representative hydrophones of each group.

Hydrophone	**Fireface 800, -3 dB**	**Fireface 800, -6 dB**	**USB-6251, -3 dB**	**USB-6251, -6 dB**
H1	16-25,000 Hz	10-40,000 Hz	-	-
H3	400-80,000 Hz	250-80,000 Hz	-	-
H5	-	-	2,500-160,000 Hz	1,600-250,000 Hz

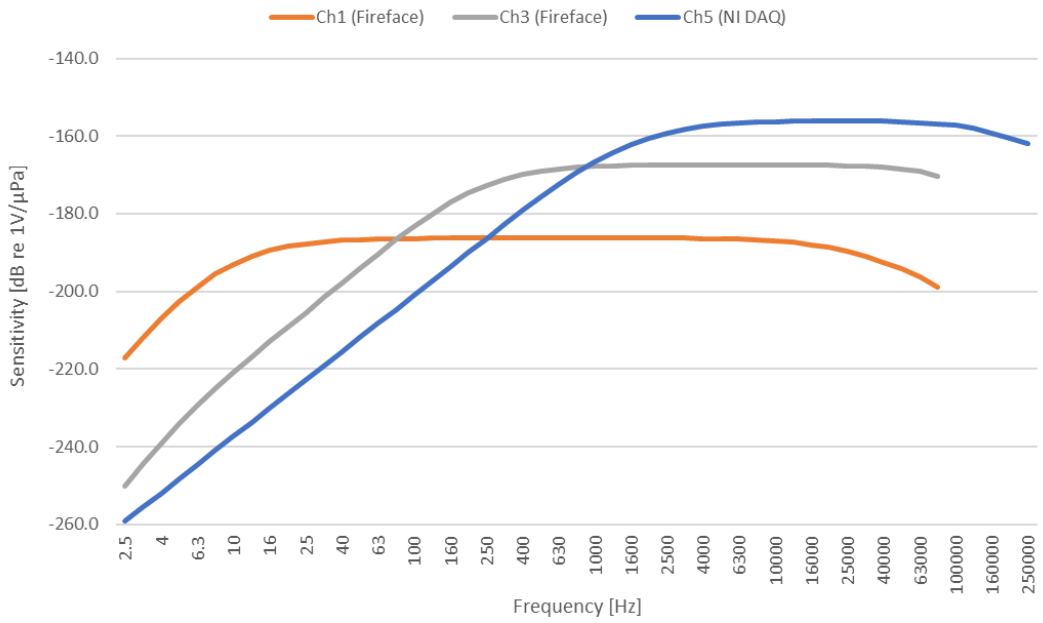

Fig. 14 System frequency response curves showing channel sensitivity for representative hydrophones of the H1-H2, H3-H4 and H5-H6 groups.

Calibration Values for PAM Software

Pamguard Array Manager

H1 (Ch0, 0.01-24 kHz) Sensitivity = -196.0 dB re: 1 V/uPa, Preamplifier Gain = +21.0 dB

H2 (Ch1, 0.01-24 kHz) Sensitivity = -195.5 dB re: 1 V/uPa, Preamplifier Gain = +21.0 dB

H3 (Ch2, 0.2-200 kHz) Sensitivity = -195.9 dB re: 1 V/uPa, Preamplifier Gain = +39.8 dB

H4 (Ch3, 0.2-200 kHz) Sensitivity = -195.9 dB re: 1 V/uPa, Preamplifier Gain = +39.8 dB

H5 (Ch4, 2-200 kHz) Sensitivity = -195.9 dB re: 1 V/uPa, Preamplifier Gain = +39.8 dB

H6 (Ch5, 2-200 kHz) Sensitivity = -195.7 dB re: 1 V/uPa, Preamplifier Gain = +39.7 dB

Pamguard Sound Acquisition

NI USB-6251

Terminal Configuration .....Differential

Input Voltage Range.....4 V (set as +/- 2 V per channel)

Additional System Gain .....0 dB

Channels.....SW Ch0 / HW Ch4, SW Ch1 / HW Ch5

Sample Rate .....up to 500 kHz

Sample Size.....16 bit

RME Fireface 800

Line Level Input .....-10 dBV (set in the Fireface Settings utility)

Input Voltage Range (p-p) .....2 V (i.e., +/- 1 V)

Additional System Gain .....-11.3 dB

Channels.....SW Ch0 / HW Ch0, SW Ch1 / HW Ch1

.....SW Ch2 / HW Ch2, SW Ch3 / HW Ch3

Sample Rate .....48-192 kHz

Sample Size.....24 bit

Depth Sensor

The array section is terminated with a piezoresistive pressure sensor.

Pressure Sensor Rating.....10 bar

Working Depth Range .....0-100 m (overpressure limit = 200 m)

ADC.....Measurement Computing USB-1208 LS

Range.....-2.5 to +2.5 V

Hardware Channel.....0

Pamguard Calibration.....Depth (m) = 64.8 * Voltage + 67.3 offset

Calibration Methods

Recording Chain Components

At Seiche Ltd., we measure the gain response of the individual electronic components of our PAM systems as a quality control process, immediately after purchase or manufacture. The same procedure, with slight differences, is followed when measuring the frequency response of preamplifiers, buffer boards, and data-acquisition units (DAQs).

The National Instruments DAQ NI-6251 is at the heart of the calibration approach. Currently, we use two in-house software applications (coded in MATLAB and LabView) to automate the measurement process. Both applications work in a similar way, producing a sequence of short tone bursts of increasing frequency, which are sent to the input of the Device Under Test (DUT) via the NI-6251, and are simultaneously recorded by the NI-6251 from the output of the DUT. The output tones from the DUT's are 'gated' and band-filtered to minimise the effect of contaminating noise. Gain is then calculated as the ratio between the root-mean-squared (RMS) voltage of the band-filtered output and the input at each measured frequency. The frequency response is presented in decibels, as 20 x $\log_{10}$ voltage gain.

A Faraday cage is used for the calibration of small components, such as preamplifiers and buffer boards, to reduce the contamination from electromagnetic interference. For larger devices, such as DAQ units, band-filtering techniques are most effective.

Hydrophone at Low Frequency

The low frequency sensitivity of all piezo-electric ceramics is measured before these are 'potted' onto a hydrophone cable using Robnor Resinlab EL225D/Bk. For this purpose, we use a relative *pressure-field* calibration method with a reference transducer, as described in section 10.4.1 of the BSI standard BS EN IEC 60565-2:2019 "Underwater Acoustics – Hydrophones – Calibration of Hydrophones. Part 2: Procedures for low frequency pressure calibration".

The ceramic is housed in an air-tight copper enclosure sealed at the bottom by a loudspeaker. The enclosure comprises two output terminals, connected internally to the ceramic, and an opening for the attachment of a reference microphone. The loudspeaker is driven with a constant low-frequency tone produced by a TTi TG5012A signal generator. A preamplifier is connected to the output terminals of the ceramic to adapt the impedance between the ceramic and the measuring device. The microphone is connected to a WB1372 DeltaTron power supply to polarise the capsule and condition the signal. The outputs from the ceramic and preamplifier, and the reference microphone and power

supply, are connected to an Agilent MSO-X 3024A digital oscilloscope. The RMS voltages from the three outputs are then measured and added into a spreadsheet tool for automatically calculating the sensitivity (in dB re: 1µPa) for the corresponding frequencies. The spreadsheet uses the sensitivity of the reference microphone and the gain of the ceramic's preamplifier to calculate the final sensitivity of the ceramic.

Only six frequencies, from 10 Hz to 200 Hz, are routinely calibrated. Higher frequencies cannot be accurately measured with this method, since the *pressure field* assumption is no longer valid for frequencies comparable or lower than, the largest dimension of the cavity of the enclosure, resulting in an in-homogenous pressure field. Nonetheless, the low-frequency sensitivity of the ceramic remains practically constant at frequencies lower than the mechanical resonance of the ceramic, which is of the order of 50 kHz for our spherical ceramics.

The sensitivity response of 'potted' hydrophones at low frequencies is calculated as the combination of the nominal sensitivity of the ceramic (averaged over 5 measurements from 20 Hz to 200 Hz) and the gain response of the selected preamplifier. The sensitivity response calculated in this way holds relatively high accuracy up to 10 kHz. For frequencies above 10 kHz, a high-frequency calibration approach is required.

Hydrophone at High Frequency

When required, the high frequency sensitivity of 'potted' hydrophones is measured using a relative *free-field* method with reference hydrophone, as described in section 10.4.1 of the BSI standard BS EN IEC 60565-1:2020 "Underwater Acoustics – Hydrophones – Calibration of Hydrophones. Part 1: Procedures for free-field calibration of hydrophones".

The hydrophone under test (HUT) is placed in a *pool* or large water tank at a fixed position, depth and orientation. A *projector* or emitting hydrophone is placed at a fixed distance from the HUD. A National Instruments NI-6251 DAQ is used to simultaneously generate and measure a sequence of short tone bursts. The signal sequence is sent to a 50 dB power amplifier, with flat response below the megahertz range, to drive the projector. The voltage from the HUT is measured by the NI-6251. The process is repeated by replacing the HUT with a reference hydrophone of known sensitivity. The individual tones in the sequences measured by the reference hydrophone and HUT are 'gated' and band-filtered before calculating their RMS voltage.

The measurement from the reference hydrophone is used to provide an accurate estimate of the pressure at the HUD for different frequencies. The pressure at the receiver and the measured voltage from the HUT are combined to obtain the sensitivity of the HUT, in dB re: 1V/µPa.

The burst duration, emission period and measurement repeatability are key for the success of this type of calibration. The burst duration must be short enough to ensure that individual tone bursts are not affected by reflections from boundaries in the finite-sized tank, and can then be isolated; the emission period must be long enough to ensure that the reverberant energy from a previous emission is totally dissipated; and test conditions (hydrophone locations, water temperature, cables, etc.) are carefully controlled to ensure repeatability in the results. All free-field measurements are carried out with strict control measurements to guarantee maximum accuracy within the limitations of the calibration approach (see BS EN IEC 60565-1:2020).