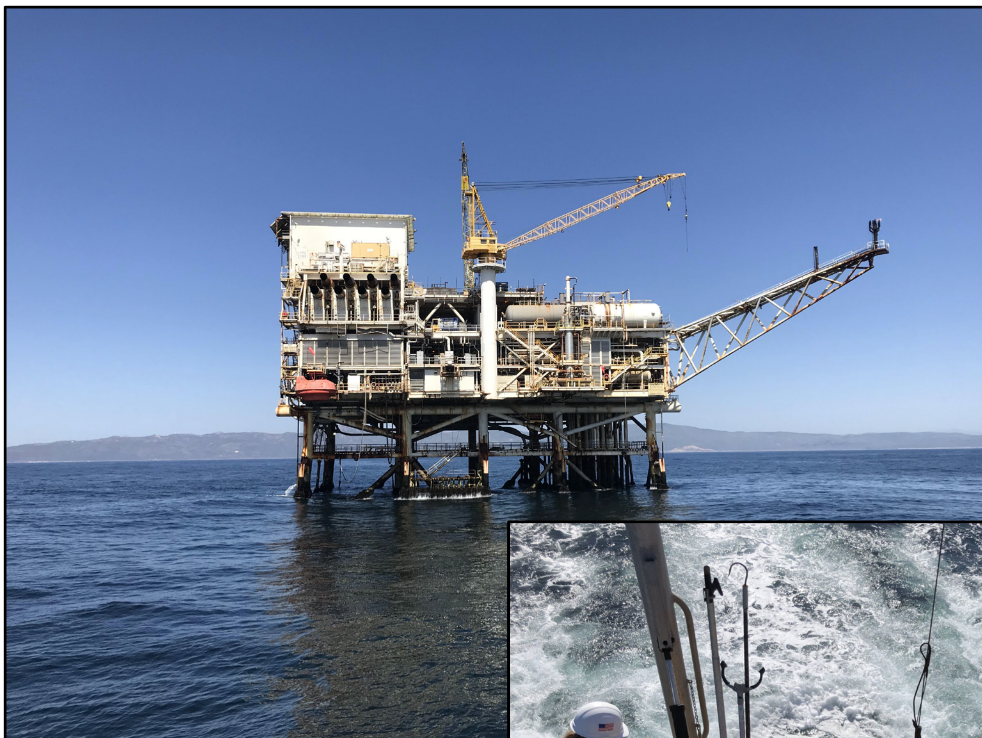
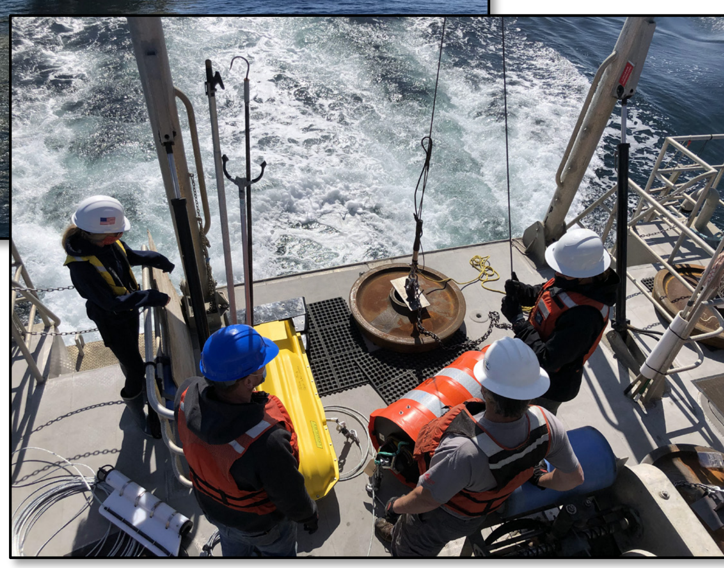
OCS Study
BOEM 2022-029

Characteristics and Contributions of Noise Generated by Mechanical Cutting During Conductor Removal Operations

Volume 1: Final Report





U.S. Department of the Interior
Bureau of Ocean Energy Management
Pacific OCS Region, Camarillo, CA

BOEM
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Volume 1: Final Report

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DISCLAIMER

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REPORT AVAILABILITY

To download a PDF file of this report, go to the U.S. Department of the Interior, Bureau of Ocean Energy Management Data and Information Systems webpage (http://www.boem.gov/Environmental-Studies-EnvData/), click on the link for the Environmental Studies Program Information System (ESPIS), and search on 2022-029.

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ABOUT THE COVER

Left photo: Photo of Platform Hermosa was taken by Kevin Fowler, Tetra Tech, Inc., during the deployment of the monitoring equipment on March 21, 2021. Right photo: Photo was taken by Kaus Raghukumar, Integral Consulting Inc., of the field team preparing to deploy the hydrophone moorings on March 21, 2021.

REPORT ORGANIZATION

Report OCS Study BOEM 2022-029 consists of three volumes:

Volume 1: Final Report
Volume 2: Appendix A: Final Field Plan
Volume 3: Appendices B ─ F
- Appendix B: Supplementary Acoustic Data
- Appendix C: Acoustic Analysis: Study Report A, Determination of Periods of Vocally Active Marine Mammals and Evaluation of Acoustic Indices
- Appendix D: Marine Mammal Acoustic Analysis: Study Report B, Development of a Deep Neural Network for Humpback Whales and Delphinids
- Appendix E: Noise Study Photo Log
- Appendix F: Hydrophone - Ocean Instruments Calibration Data

Volume 1: Final Report

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List of Abbreviations and Acronyms

as	compressional attenuation (αs)
P	physical density
°C	degrees Celsius
μPa	micropascal
ACI	Acoustic Complexity Index
AHA	Activity Hazard Analysis
AHr	ampere-hour
AIDS	Acquired Immune Deficiency Syndrome
AMP	amplitude
ANSI	American National Standards Institute
ASAP	As soon as possible
BI	Bioacoustic Index
BOEM	Bureau of Ocean Energy Management
Cal/OSHA	California Division of Occupational Safety and Health Administration
CDC	Centers for Disease Control and Prevention
CFR	Code of Federal Regulations
CHSM	Corporate Health and Safety Manager
CIH	Certified Industrial Hygienist
CINMS	Channel Islands National Marine Sanctuary
cm	centimeter
CNN	Convolutional neural network
COLREGs	The International Regulations for Preventing Collisions at Sea
CORE	CORE Occupational Medicine
Cp	compressional sound speed
CPR	cardiopulmonary resuscitation
CSP	Certified Safety Professional
CSV	comma separated value.
CTD	Conductivity, Temperature, and Depth
dB re 1 μPa2 s	decibel re 1 micropascal squared per second
dB	decibel
dBPeak	Peak Sound Pressure
DOD	Department of Defense
EHS	Environmental Health and Safety
EHSP	Environmental Health and Safety Plan
EMS	Emergency Medical Services
ESA	Endangered Species Act
ESPIS	Environmental Studies Program Information System
Faster-RCNN	Regional convolutional neural network
FFT	Fast Fourier Transform
Freeport	Freeport-McMoRan Oil & Gas LLC
ft	feet
GUI	graphical user interface

Harvey Challenger	Freeport vessel
HAZWOPER	Hazardous Waste Operations and Emergency Response
HF	high-frequency
Hidalgo, Harvest and Hermosa	Three Point Arguello Unit Platforms
HIPPA	Health Insurance Portability and Accountability Act of 1996
Hz	hertz
IDLH	immediately dangerous to life and health
in	inches
Integral	Integral Consulting Inc.
Integral	Integral Consulting Inc.
kg/m3	kilogram per cubic meter
kHz	kilohertz
km	kilometers
lb.	pound
LE	Sound Exposure Level
LF	low-frequency
LPK	Peak Sound Pressure
LTSA	Long-term Spectral Average
m	meter
m/s	meters per second
Magnuson-Stevens Act	Magnuson-Stevens Fishery Conservation and Management Act
MATLAB	Proprietary multi-paradigm programming language and numeric computing environment developed by MathWorks.
Mdn	median
MERIDIAN	Marine Environmental Research Infrastructure for Data Integration and Application Network
MF	mid-frequency
mi	mile
MMO	Marine Mammal Observer
MMPA	Marine Mammal Protection Act
NDSI	Normalized Difference Soundscape Index
NEPA	National Environmental Policy Act
nmi	nautical mile
NOAA	National Oceanic and Atmospheric Administration
NOAA Fisheries	National Oceanic and Atmospheric Administration National Marine Fisheries Service
Noise Survey	Removal, Abrasive-cutting Noise Field Survey
NoiseSpotter™	particle motion monitoring mooring system
NRC	National Response Center
NTM	Notice to Mariners
NWS	National Weather Service
OSA	Ocean Science Analytics
OSHA	Occupational Safety and Health Administration
PAM	Passive Acoustic Monitoring

PE	parabolic equation
PESM	Project Environmental Safety Manager
PFD	personal flotation device
PL	Public Law
PPE	personal protective equipment
PS	Principle Scientist
PSD	power spectral density
PSO	Protected Species Observers
PST	Pacific Standard Time
PTS	permanent threshold shift
PW	pinnipeds in water
QA/QC	quality assurance / quality control
Resnet	Residual neural network
RMS	root mean square
ROV	remotely operated vehicle
RPM	revolutions per minute
R/V	Research Vessel
SAR	Search and Rescue
SDS	Safety Data Sheet
SEL	sound exposure level
SELcum	Cumulative sound exposure
SHSP	site health and safety plan
SNR	signal to noise ratio
SPL RMS	root mean square sound pressure level
SPL	sound pressure level
spp.	Species
SSHO	Site Safety and Health Officer
SSO	site safety officer
SSP	surface salinity profile
Study	Characteristics and Contributions of Noise Generated by Mechanical Cutting During Conductor-removal Operations Project
SUB	Streamlined Underwater Buoyancy
Survey Manager	Conductor Removal, Abrasive-cutting Noise Field Survey Manager
TB	terabyte
Tetra Tech	Tetra Tech, Inc.
TOTAL	Tetra Tech database - Tracking and Optimizing Tool for Analyzing Losses (TOTAL)
TTS	temporary threshold shift
U.S. DOI	United States Department of Interior
U.S.	United States
U.S.C.	United States Code
UL	Underwriters Laboratories
US	United States
USACE	US Army Corps of Engineers

USCG	US Coast Guard
USN	US Navy
V	volt
VHF	very high frequency
ZIP	Zero Incident Performance

Executive Summary

The Bureau of Ocean Energy Management (BOEM) has identified 23 oil platforms planned for decommissioning within federal waters offshore of southern California. Freeport-McMoRan Oil & Gas LLC (Freeport) submitted Applications for Permits to Modify (30 Code of Federal Regulations [CFR] Part 250.1704) to remove well conductors and casings on three Point Arguello Unit Platforms (Hidalgo, Harvest, and Hermosa). BOEM contracted Tetra Tech, Inc. (Tetra Tech) to characterize noise generated by abrasive cutting during conductor removal. The full title of the contracted study is "Characteristics and Contributions of Noise Generated by Abrasive Cutting During Conductor-removal Operations Study" (Study). The scope of this Study was to collect empirical data documenting the characteristics of sound pressure level (SPL) and particle motion generated by the high-pressure abrasive conductor cutting at one of the three Point Arguello Unit Platforms; however, abrasive cutting was not conducted as anticipated due to challenges Freeport encountered in the field. Mechanical cutting was used instead to facilitate conductor removal.

A field program was conducted from March 28 to April 24, 2021, at Platform Hermosa to characterize the sound from the mechanical conductor cutting. Tetra Tech managed the Study, the field effort and reporting, and subcontractor efforts. Tetra Tech deployed a series of passive acoustic monitors and analyzed those data, Ocean Science Analytics (OSA) analyzed occurrence of vocalizing marine mammals and their contribution to the soundscape from one of the acoustic monitors, and Integral Consulting Inc. (Integral) collected data related to temperature, salinity, pressure, and particle motion. Unfortunately, the particle motion component of the study was not able to be completed due to solid-state hard drive failure associated with Integral's NoiseSpotter®™ particle motion monitoring system. Data collected by Integral's thermistor chain, which comprised sensors collecting temperature data, were usable and were used to develop the site-specific sound speed profile.

The results of the field program focused on analyzing the noise contribution from mechanical cutting activities; however, existing underwater ambient noise levels were also reviewed. The average ambient noise levels within the vicinity of the study area ranged from 114 to 116 decibels (dB) SPL at an approximate distance of 100 meters (m) (328 feet [ft]) from the edge of the platform. The ambient sound levels near the platform were higher due to the noise produced from operations on the platform. Data collected during mechanical cutting events spanned 21 days from April 1, 2021, to April 21, 2021. During this period, a total of 25 wells and empty conductors were cut over 40 identified cutting events. The cut depth ranged from 6 to 8 m (20 to 25 ft) below the mudline and the cutter revolutions per minute (RPM) ranged from 60 to 72 RPM. The duration of the cuts was dependent on the number of casing strings that needed to be cut. The results showed that at a distance of 106 to 117 m (348 to 384 ft), and depending on the well that was being cut, the measured sound levels ranged from 120 to 130 dB SPL for the duration of the total cutting event. As expected, farther away those levels attenuated to 114 to 124 dB SPL at a distance of 275 to 293 m (902 to 961 ft) from the conductor being cut. The effect on octave band frequency sound levels was apparent, with wellbore cuts influencing measure sound levels significantly in the 125 to 2,000 hertz (Hz) range. Cutting of empty conductors was also analyzed, which generally showed similar measured sound levels at comparable distances; however, a broader impact on the measured spectral sound levels was observed. The difference in the frequency range between the empty conductors and the wellbore conductors is likely due to the multiple casing strings within the wellbore conductors allowing less acoustic propagation.

Other factors, such as depth of cut and cutter RPM, were reviewed to determine their influence on the measured noise level; however, there were limited data available pertaining to variation in RPM. The majority of wellbore conductors were cut at a depth of 6 m (20 ft) below the mudline; however, there were select conductors that were cut at depths of 6.7 to 7.6 m (22 to 25 ft) below the mudline. Comparison of the cutting noise for those conductors at deeper depths did not show an appreciable change

in measured sound levels but it is recognized that additional data would be helpful to evaluate that comparison comprehensively.

Further analysis showed that similar measurement results were observed at monitor positions at mid-water column depth and at the bottom of the water column, indicating that the noise generated from cutting not only occurs at or below the mudline but also through the length of the conductor. In addition, the sound generated by the cutting operations significantly increased the ambient sound levels in the vicinity of the platform. The wellbore cutting operations resulted in a 14 to 27 dB increase over the existing ambient sound levels and the empty conductor cuts resulted in an increase of 18 to 33 dB over the existing ambient sound levels. In support of the conductor cutting operations, the Motor Vessel (M/V) *Harvey Challenger* (Freeport's dynamically positioned supply vessel) was present for approximately 25 percent of the cutting events. The influence of vessel activity was evaluated as part of the Study analysis, and it was found that sound exposure (SEL) levels for the duration when only the mechanical cutting occurred ranged from 169 dB near the conductor to 163 dB at 280 m (918 ft) from the platform. Vessel activities were found to have a 1 to 4 dB influence on SPL root mean square levels and a 3 to 5 dB influence on SEL levels. Supplementary analyses included review of the directionality of the conductor cutting activities relative to the platform and completing sound propagation modeling to determine the distances to the marine mammal permanent threshold shift (PTS) onset as well as the marine mammal and fish behavioral response thresholds as prescribed by the National Oceanic and Atmospheric Administration, National Marine Fisheries Service. Results of the modeling showed that mechanical cutting activities do not generate noise levels high enough to exceed the thresholds for marine mammal PTS onset. The distance to threshold for fish behavioral response is less than 10 m (33 ft) from the source and the marine mammals' behavioral response distance ranges from 205 to 663 m (673 to 2,175 ft).

Marine mammal presence was also reviewed during the field program although the noise sources related to cutting activities and other sound sources such as from ship traffic made detection challenging. The analyses showed that humpback whales occurred most frequently and were noted in over half of the total deployment duration, followed in frequency of occurrence by delphinid species. Sperm whales were not encountered often and were recorded only intermittently during three events; likely these were distant animals. As the analysis was limited to a single acoustic station, the distance of the marine mammals relative to the platform could not be accurately determined. Conversely, general information can be provided about the detection distances of the most frequently detected species (i.e., humpback whales and delphinid species). Detection distances for humpback whale calls are significantly impacted by regional bathymetric characteristics and ambient sound levels due to their variable source levels and frequency ranges. The marine mammal call frequency was also evaluated in response to cutting noise. It was determined that the humpback whale dataset was best for this analysis due to its larger sample size; however, due to an insufficient number of calls and the low signal to noise ratio, the sample size was still not large enough to effectively conduct the call frequency analysis. Marine mammal presence was further reviewed with the use of several acoustic indices as well as implementation of a deep neural network. The objective of this effort, to develop a deep neural network that successfully detects marine mammal sounds of interest and reduces detection of noise within a large passive acoustic dataset, was successful.

This study is the first of its kind to undertake an approach for assessing mechanical cutting noise in Pacific waters associated with removal of oil platform conductors. The findings are novel and precedent setting and provide a baseline for future comparisons as well as a foundation of data for use in impact evaluations for marine biological resources including marine mammals, fish, and sea turtles. Acoustic data and marine mammal analyses provided meaningful results that can be used to inform future studies evaluating potential underwater acoustic impacts of mechanical conductor cutting activities. Recommendations for future similar studies are provided to assist with more refined data collection and analysis.

1 Introduction

The Bureau of Ocean Energy Management (BOEM) has identified 23 oil platforms planned for decommissioning within federal waters offshore of southern California. Freeport-McMoRan Oil & Gas LLC (Freeport) submitted Applications for Permits to Modify (30 Code of Federal Regulations [CFR] Part 250.1704) to remove well conductors and casings on three Point Arguello Unit Platforms (Hidalgo, Harvest, and Hermosa). BOEM contracted Tetra Tech, Inc. (Tetra Tech) to characterize sound generated by abrasive cutting during conductor removal. The full title of the contracted study is "Characteristics and Contributions of Noise Generated by Abrasive Cutting During Conductor-removal Operations Study" (Study). The scope of this Study was to collect empirical data documenting the characteristics of sound pressure level (SPL) and particle motion generated by the high-pressure abrasive conductor cutting at one of the three Point Arguello Unit Platforms, along with the measurement of temperature, salinity, and pressure to characterize the sound speed profile during the cutting operations. The collected data were intended to be used to understand sound pressure and particle motion levels generated during cutting activities and aid in the estimation of the azimuthal variability for future sound propagation modeling analysis and quantification of potential underwater noise impacts on marine species. However, abrasive cutting was not conducted as anticipated due to challenges Freeport encountered in the field. Instead, mechanical cutting was used to facilitate conductor removal. This volume (Volume 1: Final Report) describes the field measurement equipment, monitoring station locations, approach, and results of the mechanical conductor cutting activities that were completed at Platform Hermosa.

1.1 Study Background

Freeport deployed equipment and personnel to remove 62 total conductor casings (14 at Platform Hidalgo, 19 at Platform Harvest, and 29 at Platform Hermosa) over a period of approximately nine months. The cutting time for each conductor varied from approximately 42 minutes to 26 hours depending on the number of casing strings that needed to be cut per conductor. Conductor cutting started at the Platform Hidalgo on January 22, 2021 and then progressed to Platform Hermosa in March 2021. Platform Hermosa was the focus of the Study. The field program occurred at Platform Hermosa between March 28 and April 24, 2021. This time span is inclusive of field mobilization and demobilization periods. The data collection timeframe was April 1 to April 21, 2001. Conductor-cutting activities at Platform Harvest were slated to take place after they concluded at Platform Hermosa.

A series of passive acoustic recorders were deployed by Tetra Tech to monitor the noise contribution generated by the mechanical conductor cutting operations at Platform Hermosa. Additionally, subcontractors Ocean Science Analytics (OSA) and Integral Consulting Inc. (Integral) supported the Study. OSA provided data and findings through analyzing occurrence of vocalizing marine mammals and their contribution to the soundscape. Integral was retained for the collection of temperature, salinity, pressure, and particle motion data. With the noise data collected, OSA was able to analyze both the presence and contribution of marine mammals to the soundscape and evaluate the utility of three acoustic indices for their potential in rapidly identifying periods of marine mammal sounds and cutting noise. Unfortunately, the particle motion component of the study was not able to be completed due to solid-state hard drive failure associated with Integral's NoiseSpotter®™ particle motion monitoring system. Data collected by Integral's thermistor chain, which comprised sensors collecting temperature data, were usable and applied to develop the sound speed profiles used for sound propagation modeling.

Once the team learned that the failed hard drive could not be repaired in time for particle motion data analyses to be incorporated into this report, Tetra Tech proposed three supplementary studies. Tetra Tech recommended these studies to BOEM, which approved them for inclusion in this study on December 3, 2021. These additional studies utilized the acoustic data that were collected and are summarized below:

1. Further analysis of the Study measurement data was completed to include the National Oceanic and Atmospheric Administration's National Marine Fisheries Service (NOAA Fisheries) weighted measured results. These data can be more easily compared to the relevant injury and disturbance criteria identified by NOAA Fisheries (2018) to evaluate potential impacts to marine species.
2. A sound propagation modeling analysis of the conductor-cutting activities measured for the Study was performed. This was accomplished using the software dBSea which predicted propagation of underwater sound levels beyond the footprint of the Study monitoring area
3. An additional marine mammal analysis was completed using a deep neural network developed and evaluated in PAMGuard. The multi-species network was based on the types of calls detected during the field deployment. The performance of the deep neural network was reviewed to determine the possibility of using this type of network to detect similar calls within similar field programs and monitoring activities.

These sets of analyses contained in this Final Report for the Study are intended to provide BOEM with information regarding the overall characteristics of sound produced by the mechanical cutting processes in Pacific Ocean waters. These data will inform future National Environmental Policy Act (NEPA) and other environmental impact analyses, and provide precedent-setting results on SPLs and SELs produced by mechanical cutting.

The seven sections in this volume of the report (Volume 1) provide background on the Study; a description of methods, results and findings; a series of recommendations for future work, and a reference section that is part of a supplementary EndNote library. The report appendices are divided into two volumes: Volumes 2 and 3 of the Report provide supplementary information in a total of six appendices. A summary list of appendices is provided below.

- **Volume 2, Appendix A: Final Field Plan.** Provides details regarding the mobilization and demobilization of Study equipment, the vessel used, and equipment specifications.
- **Volume 3, Appendix B: Supplementary Acoustic Data.** This appendix includes additional acoustic data analyzed by Tetra Tech beyond those presented directly in the body of the report (Volume 1).
- **Volume 3, Appendix C: Acoustic Analysis: Study Report A, Determination of Periods of Vocally Active Marine Mammals and Evaluation of Acoustic Indices**. This is first of two reports provided by the Tetra Tech subcontractor OSA. Appendix C details the marine mammal analyses including findings on occurrence and vocalizations, an investigation of the use of novel acoustic indices for marine mammal calls, and recommendations for future marine mammal studies related to cutting work. Portions of Appendix C have been excerpted into the main body of this report.
- **Volume 3, Appendix D: Marine Mammal Acoustic Analysis: Study Report B, Development of a Deep Neural Network for Humpback Whales and Delphinids.** This is the second of two reports provided by the Tetra Tech subcontractor OSA. This section details development of a deep neural network for humpback whales and delphinids. The marine mammal analyses and findings were completed by OSA. Portions of Appendix D have been excerpted into the main body of this report.
- **Volume 3, Appendix E: Noise Study Photo Log**. Provides photographs of the Study mobilization, equipment deployment, and demobilization.
- **Volume 3, Appendix F: Hydrophone - Ocean Instruments Calibration Data.** Provides equipment calibration data.

1.2 Mechanical Conductor Cutting Description

Prior to decommissioning a platform sometimes involves the removal of well conductors or vertical pipes that are part of the well construction (Figure 1). Before the conductors and other well pipes are cut and removed, the wells are first plugged and abandoned according to strict regulatory requirements. In this type of decommissioning approach, after this work is completed, the remainder of the platform is appropriately decommissioned. Mechanical conductor cutting employs hydraulically actuated, crushed tungsten carbide-tipped knives that are rotated from surface and mill through well casings. The mechanical cutter is run into the conductor to a minimum of 5 meters [m] (15 feet [ft]) below the mudline. Once the cutter is in position, the cut is started. Once all of the casing strings are cut, which may require multiple trips in and out of the well with different sets of knives, the cutter is pulled to surface and the mechanical cut is complete. The completed mechanical cut of the well or conductor can then be verified, or “proved,” by using a set of hydraulic jacks that will lift the cut conductor up 0.3 to 0.6 m (1 to 2 ft) and then set the conductor back down. Once all of the wells and conductors are cut, they are then pulled, sectioned, and removed from the platform.

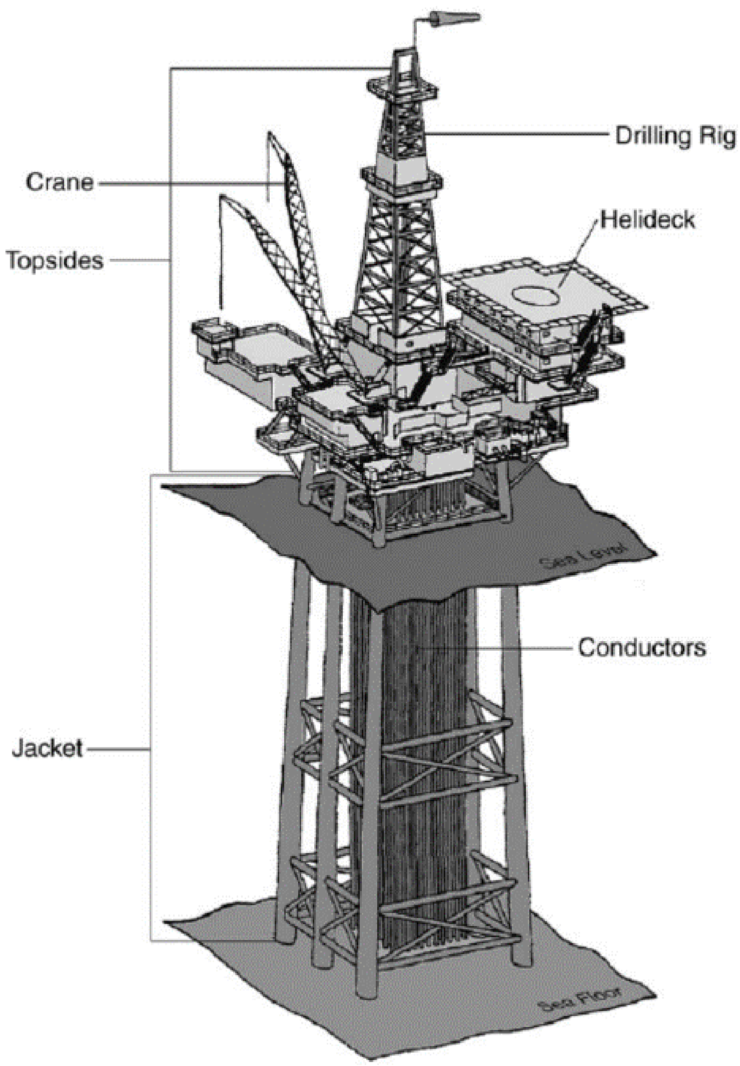


Figure 1. A Typical Oil and Gas Production Platform in Southern California (Schroeder et al. 2004)

1.3 Purpose and Objectives

The main purpose of this Study is to document the acoustic characteristics generated by mechanical conductor cutting. The objectives of this Study are as follows:

- Quantify SPLs for mechanical cutting during conductor removal, including directionality.
- Determine the distances, and at what levels, sound from mechanical cutting propagates.
- Describe and, to the extent possible, quantify the ambient soundscape prior to, during, and after mechanical cutting.
- Determine whether mechanical cutting contributes to the ambient soundscape, and if so, provide a quantification of that contribution.

Research shows that the frequency levels of anthropogenic sounds can result in impacts on marine wildlife. Sound outside the hearing range of the animal would be unlikely to affect its hearing, while the sound energy within the hearing range could be harmful. Under the NOAA Fisheries (2018) guidance, recognizing that marine mammal species do not have equal hearing capabilities, five hearing groups of marine mammals are defined as follows:

- Low-frequency (LF) Cetaceans—This group consists of the baleen whales (mysticetes) with a collective generalized hearing range of 7 hertz (Hz) to 35 kilohertz (kHz).
- Mid-frequency (MF) Cetaceans—This group includes most of the dolphins, all toothed whales except for *Kogia* species (spp.), and all the beaked and bottlenose whales with a generalized hearing range of approximately 150 Hz to 160 kHz (renamed high-frequency cetaceans by Southall et al. [2019] because their best hearing sensitivity occurs at frequencies of several tens of kHz or higher).
- High-frequency (HF) Cetaceans—This group incorporates all the true porpoises, the river dolphins, *Kogia* spp., dolphin species in the family Delphinidae from the genus *Cephalorhynchus*, and two species of *Lagenorhynchus* (Peale's and hourglass dolphins) with a generalized hearing range estimated from 275 Hz to 160 kHz (renamed very high frequency cetaceans by Southall et al. [2019] since some species have best sensitivity at frequencies exceeding 100 kHz).
- Phocid pinnipeds Underwater—This group consists of true seals with a generalized underwater hearing range from 50 Hz to 86 kHz (renamed Phocids carnivores in water by Southall et al. [2019]); and
- Otariids Underwater—This group includes sea lions and fur seals with a generalized underwater hearing range from 60 Hz to 39 kHz (termed "other marine carnivores" in water by Southall et al. [2019) and includes otariids, as well as walrus [Family Odobenide], polar bear [*Ursus maritimus*], and sea and marine otters [family Mustelidae]).

Within these generalized hearing ranges, the ability to hear sounds varies with frequency, as demonstrated by examining audiograms of hearing sensitivity (NOAA Fisheries 2018; Southall et al. 2019). To reflect higher noise sensitivities at particular frequencies, auditory weighting functions were developed for each functional hearing group that reflected the best available data on hearing ability (composite audiograms), susceptibility to noise-induced hearing loss, impacts of noise on hearing, and data on equal latency (NOAA Fisheries 2018). These weighting functions are applied to individual sound received levels to reflect the susceptibility of each hearing group to noise-induced threshold shifts, which is not the same as the range of best hearing (Figure 2). NOAA Fisheries (2018) defined acoustic threshold levels at which permanent threshold shift (PTS) and temporary threshold shift (TTS) are predicted to occur for each hearing group for impulsive and non-impulsive signals (Table 1), which are presented in terms of dual metrics: cumulative SEL (SEL_{cum}; also referred to as "SEL") and peak sound pressure (L_{PK}). However, since conductor cutting activities are considered non-impulsive, only those relevant thresholds are presented in Table 1.

Table 1. Acoustic Threshold Levels for Marine Mammals (Non-Impulsive)

Hearing Group	Non-Impulsive Sounds		
	Permanent Threshold Shift Onset	Temporary Threshold Shift Onset	Behavior
Low-frequency cetaceans	199 dB $L_{E,\ 24h}$	179 dB $L_{E,\ 24h}$	120 dB L_p
Mid-frequency cetaceans	198 dB $L_{E,\ 24h}$	178 dB $L_{E,\ 24h}$	
High-frequency cetaceans	173 dB $L_{E,\ 24h}$	153 dB $L_{E,\ 24h}$	
Phocid pinnipeds underwater	201 dB $L_{E,\ 24h}$	181 dB $L_{E,\ 24h}$	

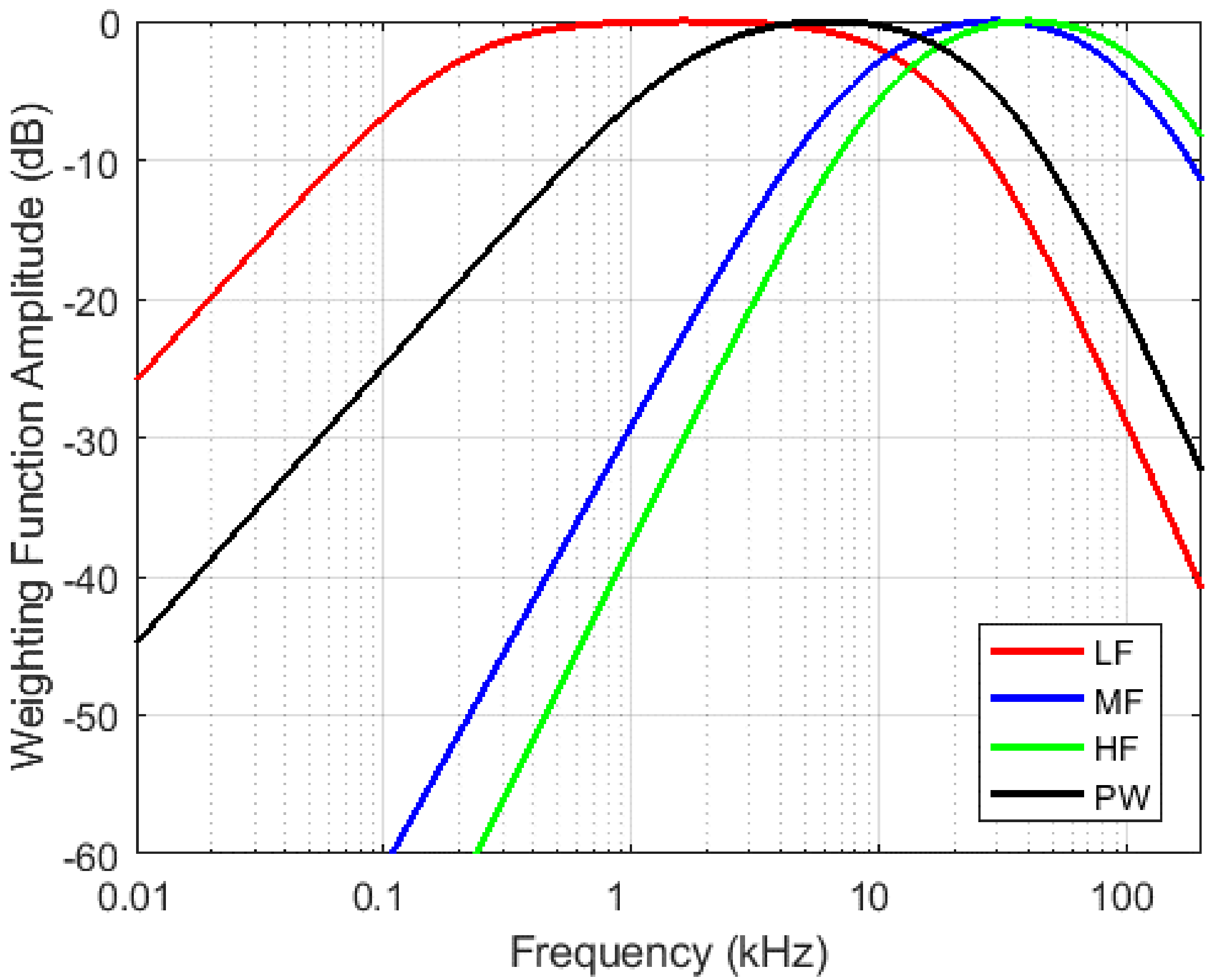
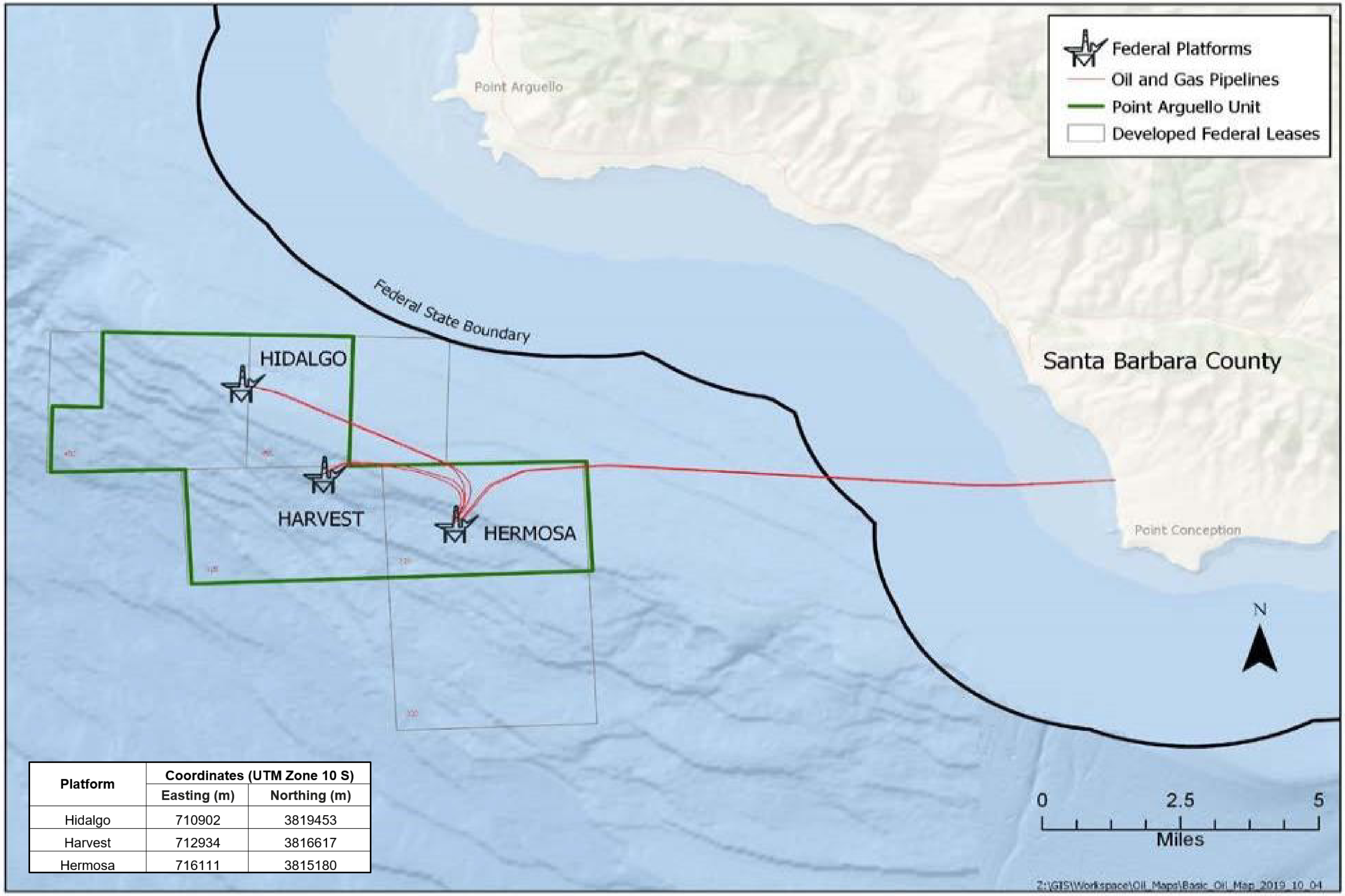


Figure 2. Auditory Weighting Functions for Cetaceans (LF, MF, and HF Species) and Pinnipeds in Water (PW). (NOAA Fisheries 2018)

1.4 Study Location and Study Area

The three Point Arguello Unit Platforms (Hidalgo, Harvest, and Hermosa) are located approximately 9 to 12 kilometers (km) (5.6 to 7.5 miles [mi]) offshore of the coast of Santa Barbara County, California (Figure 3). The water depths in the Study area range from 140 m (459 ft) to 225 m (738 ft).

This Study focused on the mechanical conductor cutting completed at Platform Hermosa, which is approximately 12 km (7.5 mi) offshore. The Study area incorporated a radius of 500 m (1,640 ft) from the Platform. The water depths within the Study area of Platform Hermosa range from 170 to 200 m (558 to 656 ft) (Figure 4).



Platform	Coordinates (UTM Zone 10 S)	
	Easting (m)	Northing (m)
Hidalgo	710902	3819453
Harvest	712934	3816617
Hermosa	716111	3815180

Figure 3. Location of Platforms Hidalgo, Harvest, and Hermosa in the Point Arguello Unit offshore Santa Barbara County, California

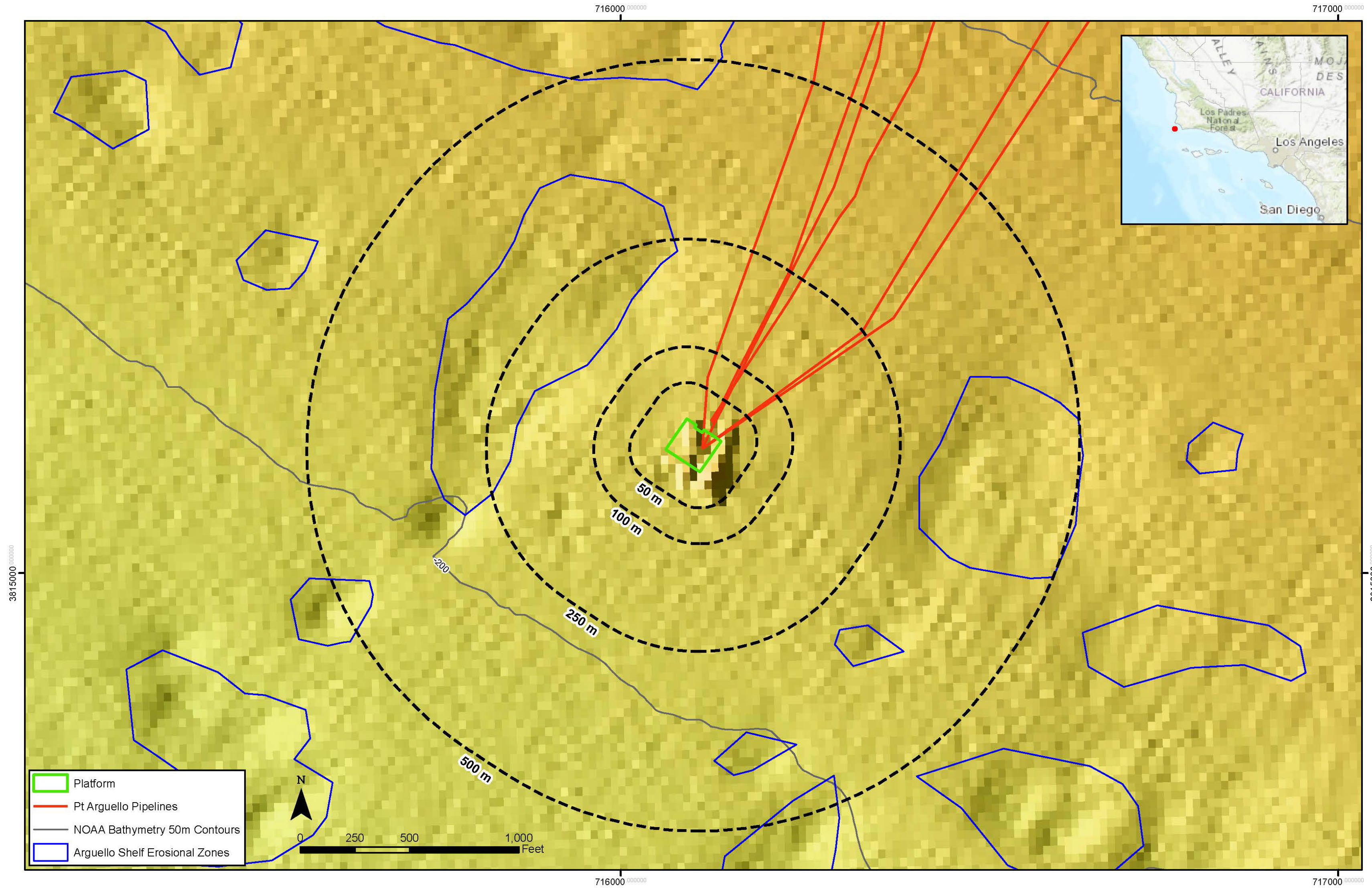


Figure 4. Location of and Bathymetry in the Project Study Area: a 500-m-radius area around Platform Hermosa

2 Equipment Mobilization, Deployment, and Recovery/Demobilization

A Field Plan (see Appendix A) with an associated Study Health and Safety Plan was developed by Tetra Tech with input from Freeport and provided to BOEM on February 26, 2021. The Field Plan considered all Study logistics, pre-field mobilization activities, and demobilization activities (Appendix A). Pre-field mobilization activities included:

- Ensuring all field personnel obtained safety gear for field operations and reviewed the Study Health and Safety Plan in advance.
- Securing necessary rigging material (e.g., load lifters, release hook, deck cleats).
- Procuring depth-specific mooring gear including lines, subsurface floats, shackles and pins, swivels, acoustic releases, etc.
- Performing a mooring assembly dry run at the Integral oceanographic laboratory for the NoiseSpotter and thermistor chain.
- Performing a mooring assembly dry run at the Tetra Tech warehouse for the acoustic monitoring moorings.
- Configuring, testing, and calibrating all monitoring equipment; and
- Shipping mooring and rigging materials to the on-site field facility, if necessary.

The equipment described in the Field Plan and deployed for this Study is summarized in Table 2. Further details regarding the full equipment specifications and detailed mooring designs can be found in Appendix A, Attachment A-2. Calibration data for all of the equipment are provided in Appendix F.

Table 2. List of Monitoring Equipment

Equipment	Purpose	Notes
NoiseSpotter	Vector sensor array that measures acoustic pressure and particle motion	3 vector sensors, 50 Hz–3 kHz bandwidth
SoundTrap 300HF	Broadband hydrophone to measure acoustic pressure	6 units at 5 locations, 10 Hz–72 kHz bandwidth
SBE 16plus V2	Conductivity, temperature, and depth	Located on NoiseSpotter Platform
Thermistor chain	Water column temperature	11 thermistors on a mooring

2.1 Equipment Mobilization

All of the equipment described in Table 2 and the field team arrived at the Santa Barbara Harbor on March 28, 2021. On-site field mobilization activities began on March 29, 2021. The on-site mobilization activities for the NoiseSpotter Platform and thermistor chain mooring system deployment required two days. The on-site mobilization activities for the SoundTrap hydrophone mooring systems required a single day. These on-site mobilization activities are summarized below:

- The NoiseSpotter system was assembled, and the acoustic release system was tested. While fully assembled, Integral tested the data acquisition systems for all sensors during a six-hour overnight burn-in test period to confirm instrumentation operational status. The Integral system did not have redundancy, using only a single solid-state hard drive for recording data.
- The SoundTrap hydrophones were assembled on the deck of the deployment vessel. The acoustic release systems were tested. The SoundTraps were field calibrated using a pistonphone calibrator. They were activated prior to being inserted into their respective enclosures and secured to the mooring for deployment.

2.2 Equipment Deployment Activities

Once the mobilization was completed, the rigging gear was organized and loaded onto the vessel. The Tetra Tech Senior Scientist and Field Team Lead led the team, including the vessel's crew, in an operations meeting and safety briefing. The vessel captain also held his own safety briefing for the team. A deployment exercise was walked through and discussed in detail as part of required Job Safety Analysis specific to the operation and the vessel. Deployment procedures and weather conditions were reviewed.

The captain of the deployment vessel, the Research Vessel (R/V) *Shearwater*, the first custom-designed scientific research vessel built by the National Oceanic and Atmospheric Administration (NOAA), was in command of the vessel and responsible for the safe operation of the vessel and vessel's company, including technical staff. The following personnel were needed for deck operations (as a minimum): two field engineers and one deck hand/equipment operator. Integral oversaw the NoiseSpotter and thermistor chain mooring deployment operations. Tetra Tech oversaw the acoustic monitoring mooring deployments. Both teams trained and worked with the crew during deployment procedures to ensure the NoiseSpotter, thermistor chain mooring, and acoustic monitoring moorings were successfully deployed in a safe manner to prevent any damage to the ship, personnel, or instrumentation. The vessel was not on site during the data collection periods for the conductor cutting; therefore, the vessel noise profile for the R/V *Shearwater* is not considered in this study.

All equipment was deployed on March 31, 2021. Deployment of the equipment moorings involved three procedures for the SoundTrap hydrophone subsurface moorings, thermistor chain subsurface mooring, and NoiseSpotter Bottom Platform. The deployment procedures used for this study are described below.

2.2.1 SoundTrap Hydrophone Subsurface Mooring Deployment

A total of four SoundTrap hydrophone subsurface moorings were deployed for this study. One mooring contained two SoundTrap hydrophones (mid-water column and bottom) and three of the moorings contained a single SoundTrap hydrophone approximately 15 m (49 ft) from the seabed. These moorings were deployed at approximate distances of 100 m (328 ft) and 250 m (820 ft) from the edge of the platform. Deployment of the SoundTrap hydrophone subsurface moorings is pictured in Figure 5. Further description of deployment procedures is given in Appendix A.

Figure 5. SoundTrap Hydrophone Subsurface-Mooring System Deployment

2.2.2 Thermistor Chain Subsurface Mooring Deployment

A single 11-element thermistor chain was deployed at a distance of approximately 500 m (1,640 ft) from the platform. This mooring was located approximately 10 m (33 ft) below the water surface. Deployment of the thermistor chain subsurface moorings is pictured in Figure 6. Further description of deployment procedures is given in Appendix A.

2.2.3 NoiseSpotter Bottom Platform Deployment

A single NoiseSpotter Platform with a conductivity-temperature-depth sensor and a SoundTrap hydrophone attached was deployed at a distance of approximately 100 m (328 ft) from the oil platform. Deployment of the NoiseSpotter is pictured in Figure 7. Further description of deployment procedures is given in Appendix A.

2.3 Equipment Recovery Activities

All of the deployed equipment featured a pop-up buoy and acoustic release system to enable efficient, safe, and reliable recovery off all deployed equipment and mooring components at the end of the study. The NoiseSpotter Bottom Platform, thermistor chain subsurface mooring, and a single SoundTrap hydrophone subsurface mooring were recovered on April 21, 2021. The three remaining SoundTrap hydrophone subsurface moorings were recovered on April 22, 2021. All monitoring equipment and mooring components, including the anchors, were recovered for all deployed systems. The recovery procedures used for this study are described in the following subsections.

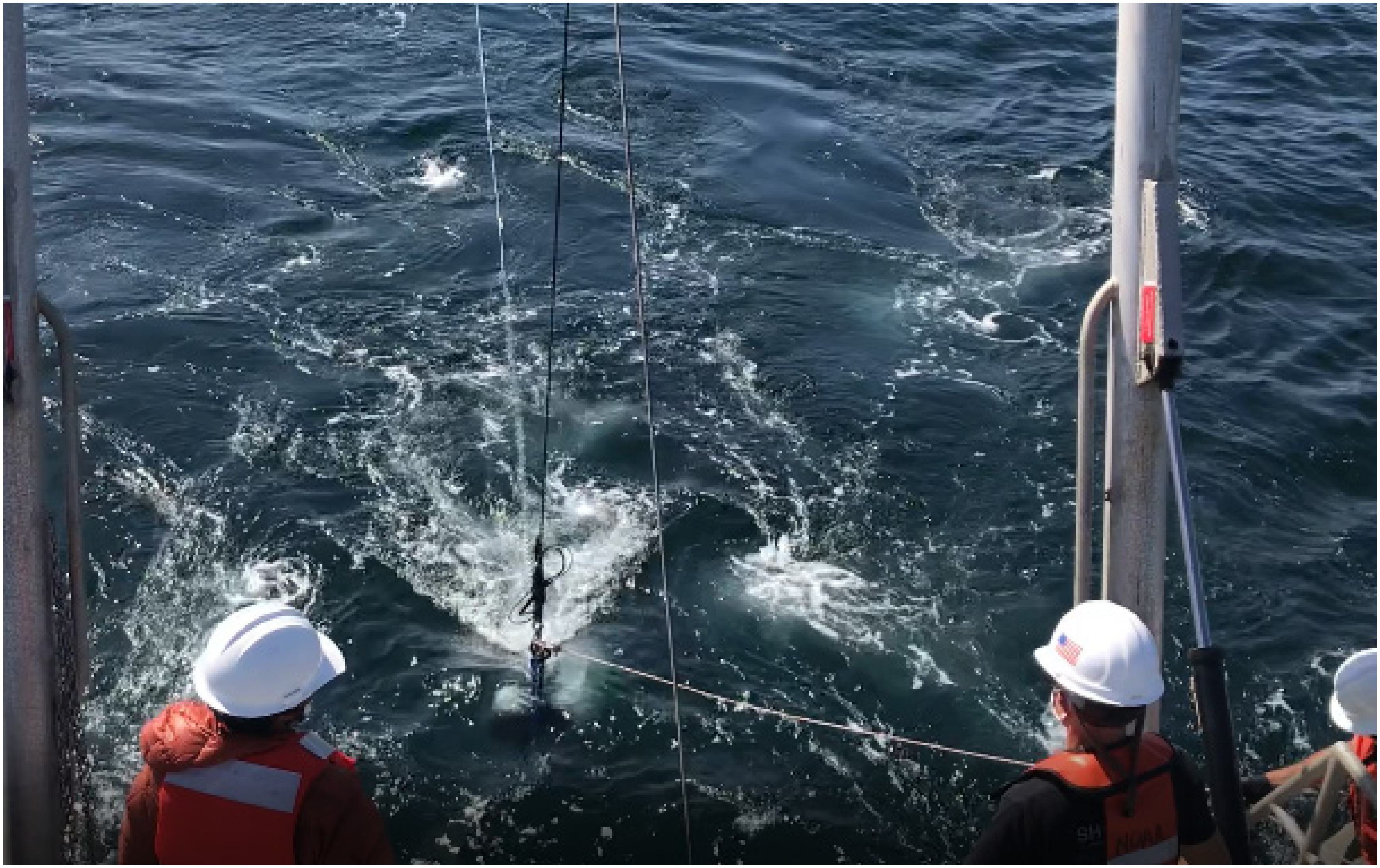


Figure 6. Thermistor Chain Subsurface-Mooring System Deployment

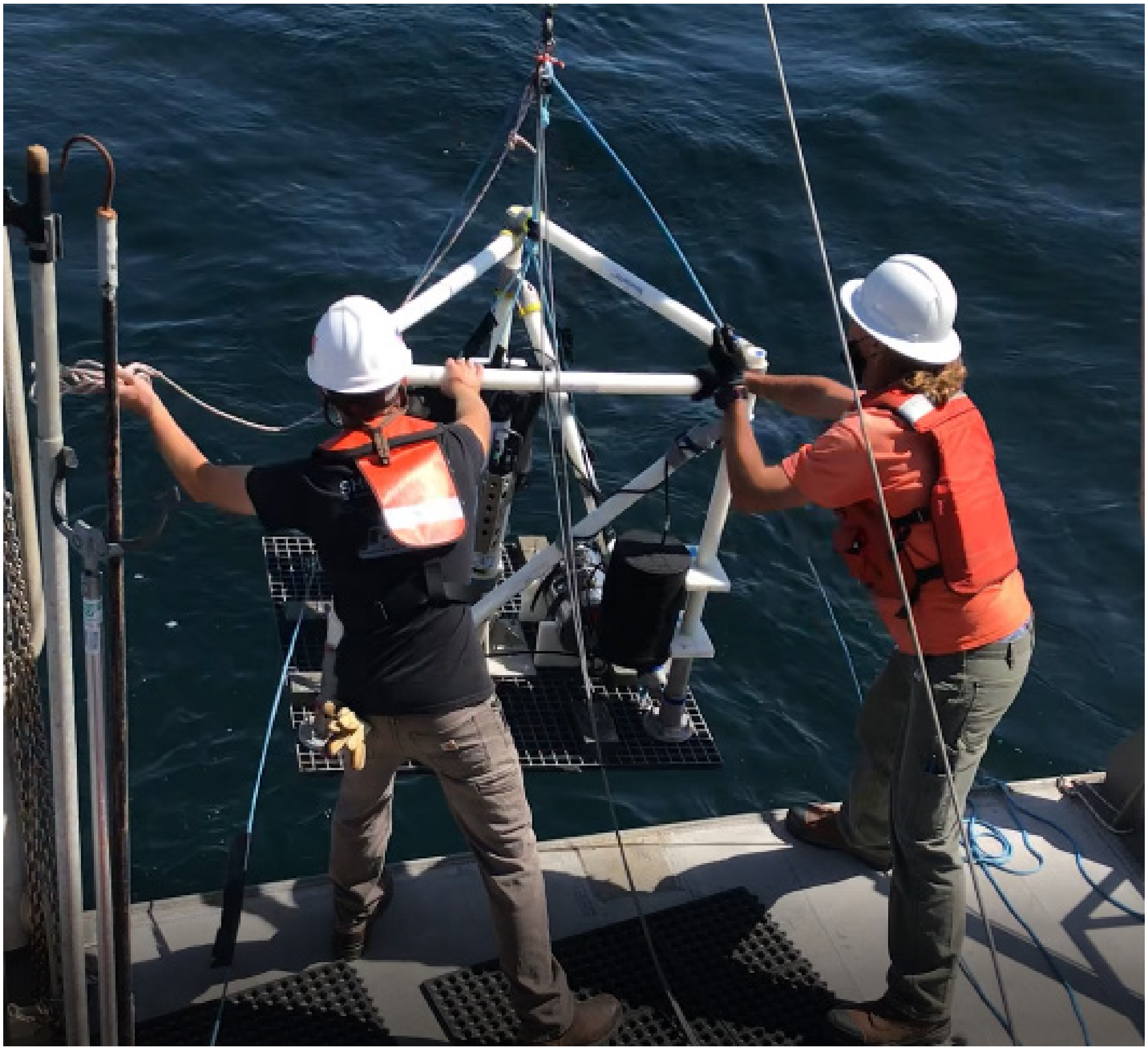


Figure 7. NoiseSpotter Bottom Platform Deployment

2.3.1 SoundTrap Hydrophone and Thermistor Chain Subsurface Mooring Recovery

To recover the SoundTrap hydrophone subsurface moorings, the vessel was positioned 100 m (328 ft) from the triangulated position determined during deployment. The respective pre-programmed releases codes were entered into the topside deck unit sending an acoustic signal to the acoustic releases allowing the recovery line to be released. This freed the trawl floats and the subsurface buoys used (SUBs-B streamlined surface buoys), allowing them to carry the monitoring equipment and recovery line to the surface. Once the equipment was visually identified, the vessel moved in for recovery when all components appeared on the surface. The mooring line was hooked or grappled and pulled into the vessel. Surface recovery of the monitoring components, trawl floats, and acoustic releases was accomplished by hand. Once the acoustic releases were recovered, the anchor retrieval line was attached to the winch and A-frame and was lifted aboard. The SoundTrap hydrophone was removed after the mooring line was fully on the vessel and secured for transport back to the marina. When the SoundTraps were removed, they were connected to a computer to download the acoustic data. All data from the six SoundTraps were successfully downloaded and stored on external hard drives.

For the thermistor chain recovery, the acoustic release was triggered to release the subsurface buoy to the surface. A canister of Dyneema line allowed the subsurface floats to rise to the surface while the mooring line was still attached. The floats were recovered with a hook and brought onboard. Once onboard, the floats were disconnected, and the line was attached to the A-frame and spooled on the winch. Thermistor and pressure sensors were cut from the line as they came up to the A-frame, allowing for the line to be spooled on the winch. The serial number of each thermistor and pressure sensor was recorded as they were removed to verify that each individual sensor was deployed at the correct depth on the mooring line. The data from the thermistor and pressure sensors were then downloaded and stored on external hard drives.

2.3.2 NoiseSpotter Bottom Platform Recovery

Similar to the subsurface moorings, the recovery of the NoiseSpotter Platform was facilitated by the acoustic release system and an acoustic deck box transponder. The vessel was positioned within 100 m (328 ft) of the bottom-lander triangulated position determined during deployment. From the vessel, the pre-programmed release code was sent to the NoiseSpotter Platform and acoustic moorings release system. A pop-up buoy was released, and a recovery line was discharged to the surface. Once the NoiseSpotter Platform was visually identified, the vessel was repositioned to orient the pop-up buoy aft of the vessel’s stern. The buoy was hooked, attached to the winch and A-frame system, and lifted onboard. The recovery line was spooled slowly until the bottom-lander was safely secured to the vessel back deck.

After the NoiseSpotter Platform was recovered, all components were secured to the back deck of the vessel for transport back to the port or marina. Integral then pulled the hard drive from the platform to download the data. It was at this point that Integral identified damage to the solid-state hard drive. Attempts to recover the data from the hard drive have not been successful to date; therefore, data from the NoiseSpotter could not be retrieved for analysis. Efforts to recover the data are continuing and, should it be repaired, Tetra Tech will deliver the hard drive to BOEM.

2.4 Demobilization of Equipment

After the equipment was recovered and the vessel returned to the marina, the following demobilization activities occurred:

- Backing up data onto separate hard drives.
- Disassembling moorings and packing components for shipping.
- Offloading of all equipment from vessel.
- Transporting the NoiseSpotter, thermistor chain mooring, and equipment to Integral.
- Shipping the acoustic monitoring mooring components to the Tetra Tech warehouse for storage; and
- Sending the SoundTraps and external hard drives to Tetra Tech's Data Manager.

2.5 Equipment Deployment Locations

The monitoring equipment collected acoustic pressure data at five locations and water property data at a single location. Data were collected continuously from April 1, 2021 through April 21, 2021. The locations of the deployed monitoring equipment are shown in Table 3 as well as in Figures 8 and 9. The distance and orientation from the monitoring equipment to the platform edge are shown in Figure 10.

Table 3. Monitoring Equipment Station Locations

Location ID	Equipment	Equipment Mount Location	Coordinates (UTM Zone 10 S)		Location Depth (m)	Distance to Platform Edge (m)
			Easting (m)	Northing (m)		
5362	SoundTrap	Bottom	716111.0	3815315.0	180	101
5363	SoundTrap	Mid-Water Column	716111.0	3815315.0	180	101
5366	SoundTrap	Bottom	716225.0	3815141.0	184	98
5365	NoiseSpotter / SoundTrap	Bottom	716060.5	3815054.1	185	100
5356	SoundTrap	Bottom	715971.0	3815165.0	189	92
5353	SoundTrap	Bottom	715898.0	3814986.0	200	252
Thermistor Chain	11 thermistors	Full Water Column	715689.9	3815449.7	193	464

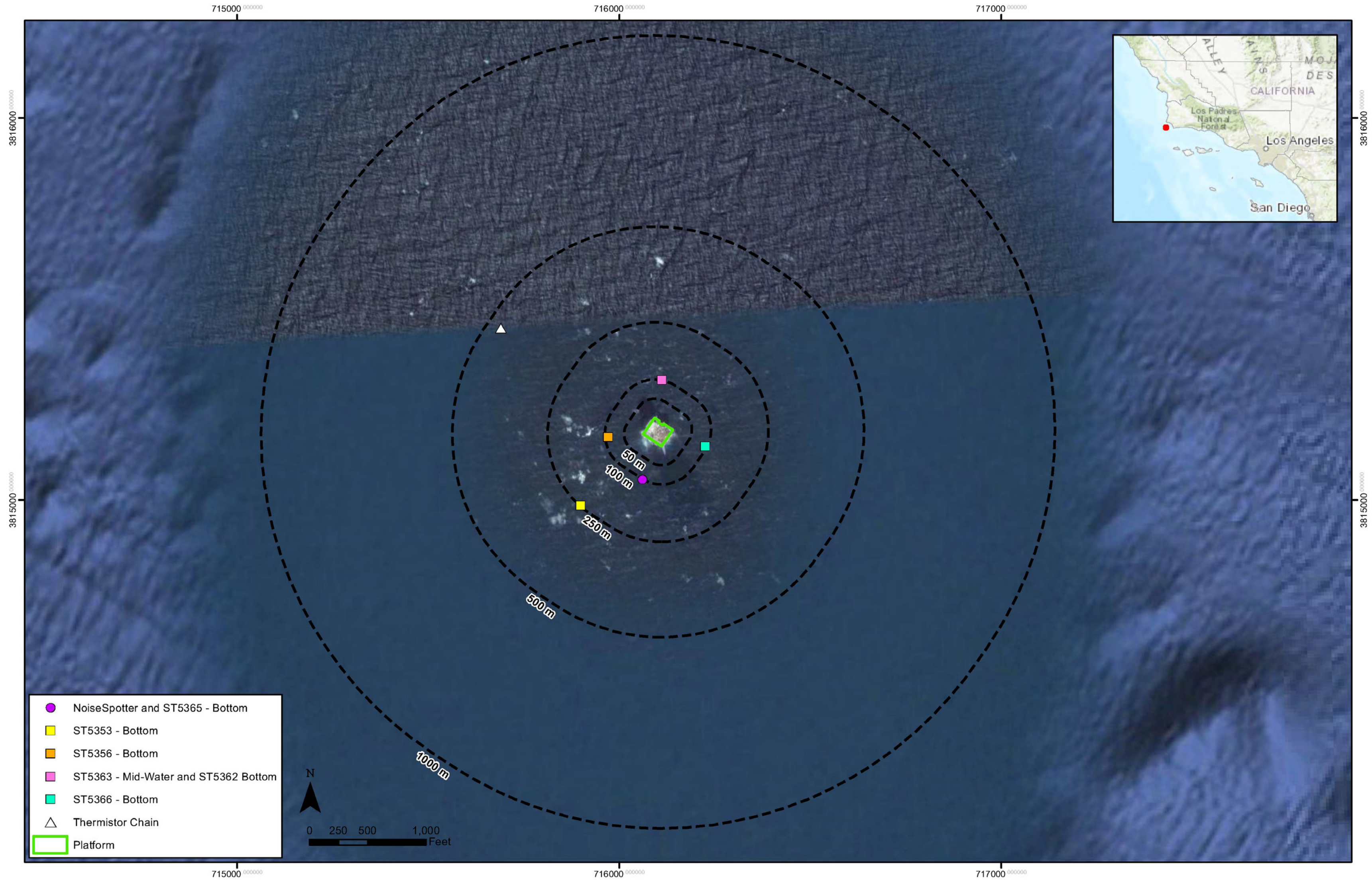


Figure 8. Study Area Aerial View and Locations of SoundTraps, Thermistor Chain, and NoiseSpotter

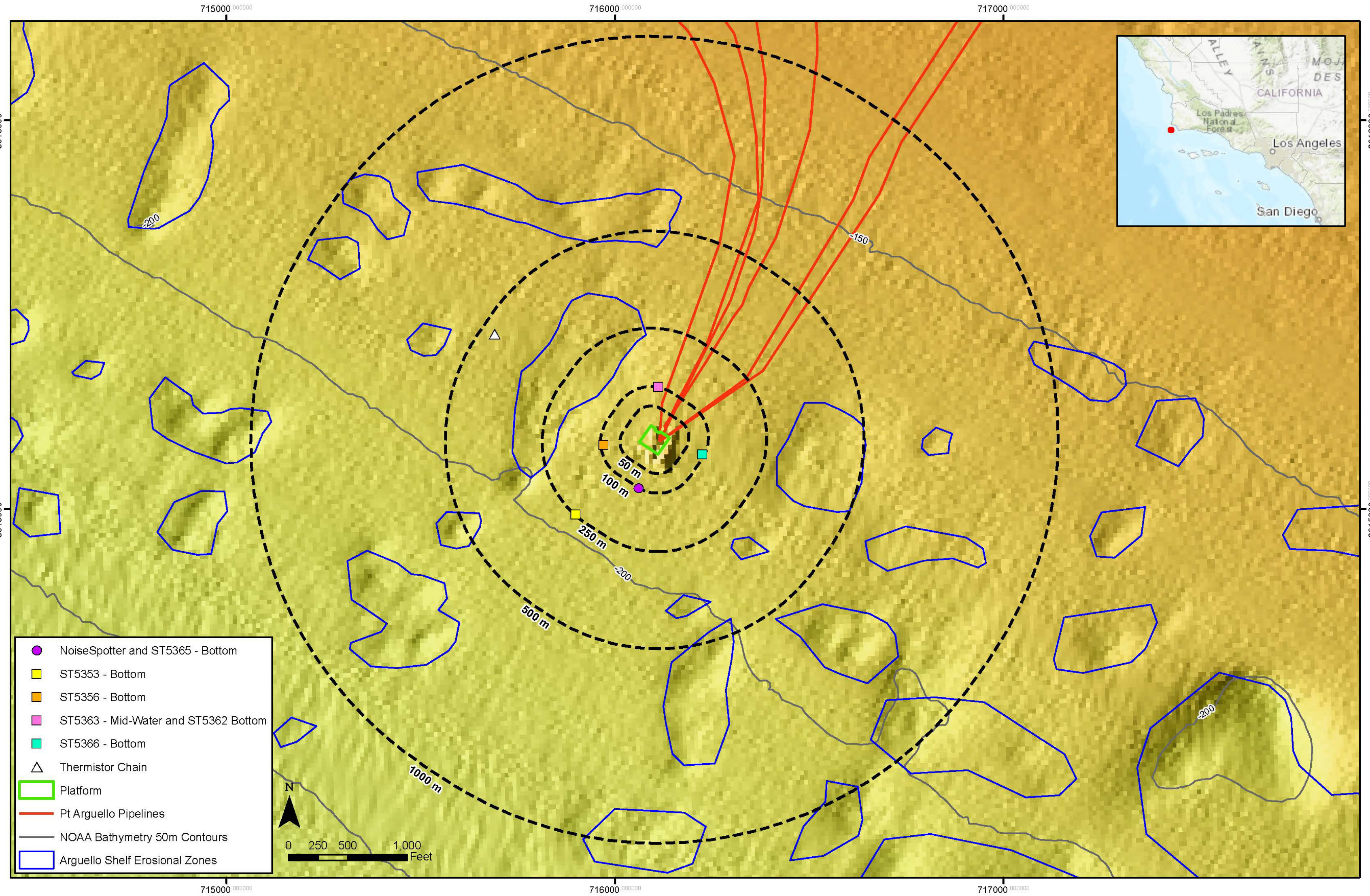


Figure 9. Study Area Bathymetry and Locations of SoundTraps, Thermistor Chain, and NoiseSpotter

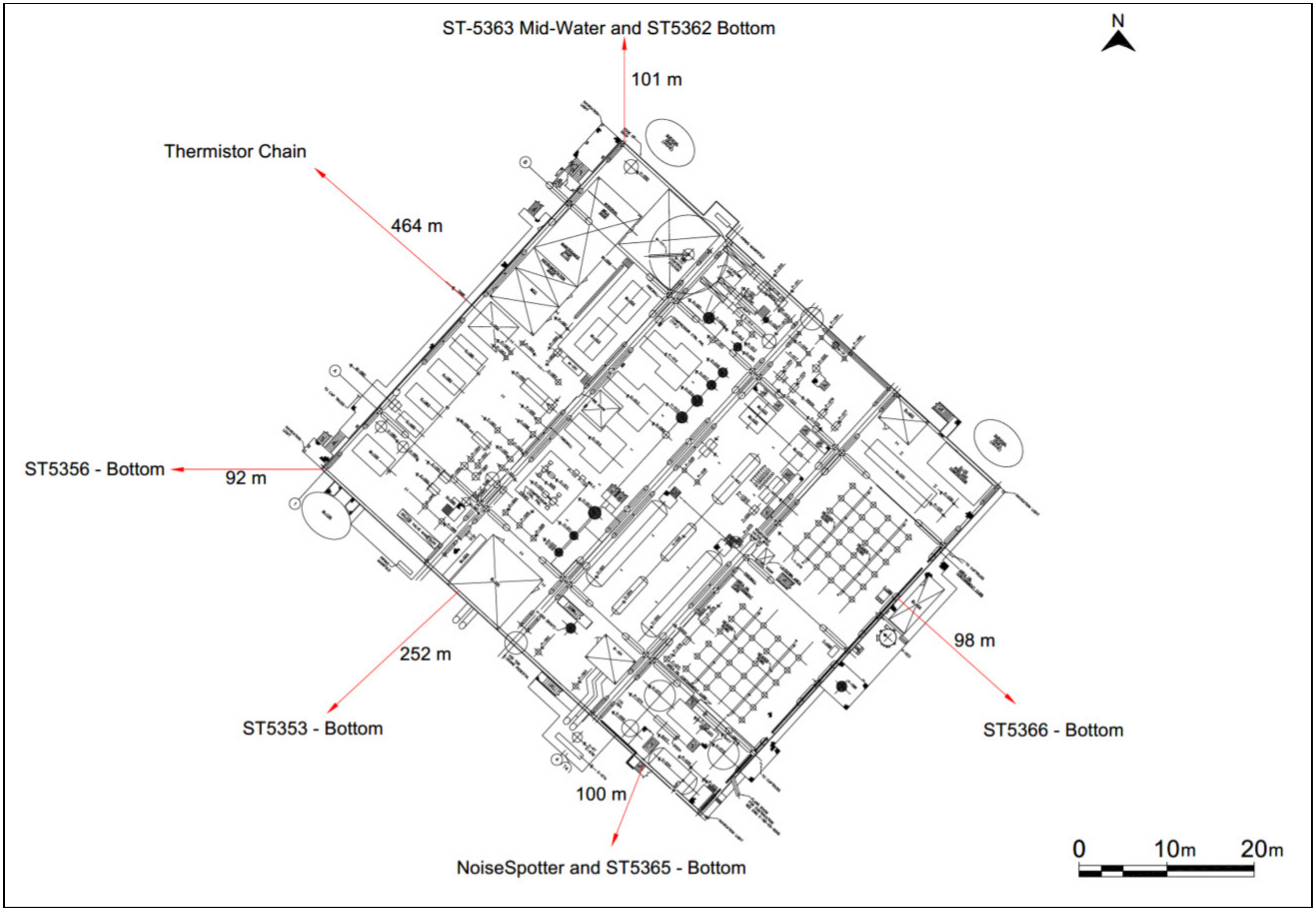


Figure 10. Monitoring Equipment Distance from Edge of Platform and Orientation to the Platform

3 Methods

The methods and tools used to process the data collected for this Study are described below. As mentioned, the particle motion data could not be retrieved; therefore, that portion of the analysis could not be completed for this report, and it is not addressed further.

3.1 Acoustic Data Processing

A total of six acoustic recorders were deployed by Tetra Tech at five locations. The data were collected from April 1, 2021, through April 21, 2021, using a sample rate of 72 kHz. All acoustic data collected were logged on to the internal memory of the SoundTraps. The data collected were in WAV file format and, once downloaded, were backed up to an external hard drive in the field. Upon return from the field, the acoustic data were also backed up on two additional hard drives.

The acoustic data were processed using dBWav, which is directly compatible with the Ocean Instruments SoundTrap hydrophones. dBWav is developed by Marshall Day Acoustics and is a tool for analyzing audio files. It handles processing of large files and long-term recordings allowing review of data sets for identification of features and trends. dBWav was used to calculate the broadband SPL, Lpk, SEL, and percentiles as well as the associated 1/3 octave band for each cut using a 1-second sampling interval for each recorded event. Additional sampling intervals were used for time history plots for clearer visual presentations of the identified data trends. dBWav was also used to determine the weighted sound pressure levels adjusted to accommodate for marine mammal hearing capabilities for comparison to criteria defined by NOAA Fisheries.

Additional data processing was completed using the MATLAB toolbox CHORUS V.8. CHORUS is a set of MATLAB routines and a standalone executable program to process, review, and analyze large datasets of underwater noise recordings made by autonomous recorders and is compatible with the Ocean Instruments SoundTraps. CHORUS was used to generate power spectral density (PSD) long-term spectrograms for the entire monitoring period using a 1-minute sampling interval and PSD spectrograms for the individual cutting events using a 10-second sampling interval.

3.1.1 Acoustic Metrics and Terminology

The sound levels presented in this Study are expressed in terms of several metrics and apply the use of exposure durations to allow for interpretation relative to potential biological impacts on marine life. NOAA Fisheries issued a Technical Guidance that provides acoustical thresholds and defines the threshold metrics. The ISO 18405 Underwater Acoustics – Terminology (ISO 2017) provided a dictionary of underwater bioacoustics for standardized terminology. Table 4 provides a summary of the relevant metrics from both NOAA Fisheries (2018) and ISO (2017) that are used within this report.

Table 4. Summary of Acoustic Terminology

Metric	NMFS (2018)	ISO (2017)		Reference Value
		Main Text	Equations and Tables	
Sound Pressure Level	SPL	SPL	L_p	dB re 1 µPa
Peak Sound Pressure Level	PK	Lpk	$L_{p,pk}$	dB re 1 µPa
Cumulative Sound Exposure Level	SEL_{cum}[a/]	SEL	L_E	dB re 1 µPa²·s

[a/]NOAA Fisheries (2018) describes the SEL_{cum} metric over an accumulation period of 24-hour period. Following the ISO standard; this will be identified as SEL in the text and L_E will be used in tables and equations of this report with the accumulation period identified.

This report follows the ISO (2017) standard terminology and symbols for the sound metrics unless stated otherwise. Below are descriptions of the relevant metrics and concepts that should help frame the discussion of acoustics in this document. The majority of the information in the following sections provides further insight into how data results have been presented in accordance with regulatory reporting requirements and established criteria.

Peak sound pressure (L_{pk} or $L_{p,pk}$; dB re 1 micropascal [µPa]) is the maximum noise level over a given event and is calculated using the maximum variation of the pressure from positive to zero within the wave. The Lpk level is commonly used as a descriptor for impulsive sound sources. At high intensities, the Lpk can be a valid criterion for assessing whether a sound is potentially injurious; however, since it does not take into account the duration or bandwidth of a signal, it is not a good indicator of loudness or potential for masking effects. The Lpk can be calculated using the formula below where *t* is the length of time. Pulses are characterized by a relatively rapid rise from ambient pressure to a maximal pressure value followed by a decay period that may include a period of diminishing, oscillating maximal and minimal pressures.

$$L_{p,pk} = 10\,log_{10}\left[\frac{max(|p^2(t)|)}{p_0^2}\right]\ dB \qquad (1)$$

Sound pressure level (SPL or L_p; dB re 1 µPa) is the root mean square (RMS) pressure level in a stated frequency band over a specified time window. It is important to note that SPL always refers to an rms pressure level and therefore not instantaneous pressure. The SPL is calculated by taking the square root of the average of the square of the pressure waveform over the duration of the time period. The SPL is also known as the quadratic mean and is a statistical measure of the magnitude of a varying quantity. Given a measurement of the time of varying sound pressure from a given noise source, the SPL is computed according to the following formula where p(t) is the instantaneous pulse pressure as a function of time, measured over the pulse duration $0 \leq t \leq T$.

$$L_P = 10\,log_{10}\left(\frac{1}{T}\int_T p^2(t)dt/p_0^2\right)\ dB \qquad (2)$$

Sound exposure level (SEL or L_E; dB re 1 µPa²·s) is similar to the SPL but further specifies the sound pressure over a specified time interval or event, for a specified frequency range. Underwater sounds are classified according to whether they are impulsive or non-impulsive. Impulsive sounds are typically transient, brief (less than 1 second), broadband, and consist of high peak sound pressure with rapid rise time and rapid decay. Non-impulsive sounds can be broadband, narrowband or tonal, brief or prolonged, or continuous or intermittent, and typically do not have a high peak sound pressure with rapid rise/decay time that impulsive sounds do. Fixed-location, non-impulsive sounds are associated with an operational offshore wind turbine. The SEL for a single event is computed from the time-integral of the squared pressure over the full event duration (T):

$$L_E = 10\,log_{10}\left(\int_T p^2(t)dt/T_0 p_0^2\right)\ dB \quad (3)$$

3.2 Sound Propagation Modeling

Underwater sound propagation modeling was completed using dBSea, a software developed by Marshall Day Acoustics for the prediction of underwater noise in a variety of environments. The model is built by importing bathymetry data and placing noise sources in the environment. Each source can consist of equipment chosen from either the standard or user-defined databases. Sound mitigation methods may also be included. The user has control over the seabed and water properties including sound speed profile, temperature, salinity, and current. Sound levels are calculated to the extent of the bathymetry area which was input into the model. To examine results in more detail, levels may be plotted in cross sections, or a detailed spectrum may be extracted at any point in the calculation area. Levels are calculated in octave or third octave bands. Three different solvers are available, and the user may choose different solvers for low frequency and high frequency ranges. Further details regarding the sound propagation modeling input and setup parameters are provided in Section 4.6.

3.3 Thermistor Chain Data Processing

The 11-element thermistor chain mooring was deployed at a single location collecting data from April 1, 2021, through April 21, 2021. This mooring consisted of the following sensors deployed at the designated depths on the same mooring line:

1. 11 Solo^3-T temperature sensors manufactured by RBR located at depths of 20 m (66 ft), 30 m (98 ft), 40 m (131 ft), 50 m (164 ft), 60 m (197 ft), 70 m (230 ft), 85 m (279 ft), 110 m (360 ft), 135 m (443 ft), 160 m (525 ft), and 185 m (607 ft). Data were collected in 1-second intervals.
2. 6 Hobo Onset water level logger at depths of 20 m, 30 m, 40 m, 50 m, 60 m, and 70 m (i.e., collocated with the Solo^3-Ts at those depths). Data were collected in 1-hour intervals.

The absence of pressure sensors below 70 m (230 ft) was justified based on the small expected vertical motion of the sensors, relative to that expected above 70 m (230 ft). Additionally, salinity measurements were made near the seabed on the NoiseSpotter® mooring using a SeaBird Scientific SBE16 instrument that provided temperature, salinity, and depth measurements, sampled every 6 seconds, and averaged onboard the instrument into 120-second (2-minute) windows.

Solo^3-T data were first converted from RBR's proprietary data format to comma separated value files using the manufacturer-provided RSK file format Tools software package. All temperature data were then averaged into 30-second windows prior to analysis to remove HF noise and to make the data more tractable to analysis. Hobo data were converted to depth in meters using the Thermodynamic Equation of Seawater-2010 Gibbs Seawater toolbox.[1]

The different start times of each of the 17 sensors required the interpolation of all data onto a uniform time axis, which was performed using a time axis spaced every 30 seconds. Additionally, due to the

[1] https://www.teos-10.org/index.htm

natural sway of the mooring, temperature measurements were not always made at identical depths over the course of the deployment. Therefore, a second interpolation step was undertaken, where all data were interpolated to the mean depth of each sensor over the deployment period. During this interpolation step, measured time-dependent depths (from the Hobo Onsets) were used above 70 m (230 ft), while the sensor depth on the mooring line was used for measurements below 70 m (230 ft).

Sound speeds were computed from the temperature, depth, and salinity measurements assuming little change in salinity over the water depth. This is a reasonable assumption, given that there are no nearby freshwater sources, and no precipitation was recorded over the deployment duration. Sound speeds were also computed using the Gibbs Seawater toolbox.

3.4 Marine Mammal Acoustic Data Processing

3.4.1 Marine Mammal Acoustic Metrics and Terminology

The three indices used in the marine mammal acoustic analysis were Acoustic Complexity Index (ACI), Bioacoustic Index (BI), and Normalized Different Soundscape Index (NDSI). These indices are described below:

- **ACI—**Recent marine-based studies have repeatedly reported that ACI, which is a direct quantification of the intensity of sounds likely to be attributable to biological sound sources, is a promising biodiversity metric (Bolgan et al. 2018; Davies et al. 2020; Pieretti et al. 2017). For example, Pieretti et al. (2017) found there to be noise associated with higher PSD levels and lower ACI levels and documented higher values in ACI at night corresponding to increased fish vocal activity. These novel studies indicate a link to changes in the biological assemblages within their respective study areas but offer caution when interpreting results and suggest ACI is specific to the particular environment. When these metrics are validated through comparison to periods of documented vocal activity, better interpretation of the metrics is possible (Haver et al. 2018). As a means of an indirect measure, the ACI may represent a quantitatively efficient and biologically meaningful indicator of the biodiversity of marine mammals found within an ecosystem.
- **BI and NDSI—**In addition to ACI, the BI and NDSI measurements are long-standing metrics used in terrestrial acoustic monitoring but are less prevalent in marine-based studies. The BI was originally developed by Boelman et al. (2007) to determine avian abundance and corresponds well with measures of avian diversity. Another worthy candidate of underwater evaluation is the NDSI, which provides an estimate of anthropogenic disturbance by finding the ratio of an anthrophony frequency band to a biophony frequency band (Boelman et al. 2007; Kasten et al. 2012). The NDSI index relies on the consistent nature of anthropogenic noise in separate frequency bands from biophony.

3.4.2 Determination of Vocally Active Marine Mammals and Evaluation of Acoustic Indices

The marine mammal analyses used the dataset from the 5353 SoundTrap (Table 2) with a sample rate of 72 kHz for a period of three weeks from March 31, 2021, through April 22, 2021, totaling 550 hours. The 5353 SoundTrap was located approximately 252 m (827 ft) from the edge of Platform Hermosa at a depth of approximately 200 m (656 ft). A detailed description of methods used both for the initial analyses and the subsequent deep learning methods of detection and classification can be found in Appendices C and D**,** respectively. An overview summary of these two sets of analyses is provided here.

Data processing for the marine mammal analyses utilized PAMGuard (version 2.01.05; Gillespie et al. 2009) using a two-stage process. PAMGuard is a widely used, open access software program that includes automated and semi-automated modules for the detection and localization of marine mammals. It is an ideal software tool for efficient review of large datasets due to the functionality available for automated and semi-automated processing and the ability to customize detection for a wide range of marine mammals (Macaulay et al. 2017; Malinka et al. 2018; Miller et al. 2016). Stage 1 was processed using PAMGuard's standard mode and involved automated detection of calls from several marine mammal species, using a combination of the click and whistle and moan detectors in PAMGuard. Stage 2 involved using PAMGuard's ViewerMode for the post-automation annotation of the automated detections. Various modules were used during annotation to expedite the review of automated detections and to parse out true detections from noise (e.g., the click detector, the long-term spectral average [LTSA]). Calls attributable to marine mammals that occur within proximity to each other were grouped into "acoustic events" by species or species group (e.g., dolphins were grouped as Delphinid species, or a specific species such as humpback whale was used when specific identifications were possible). To increase efficiency in the Stage 2 annotation process, three analysis iterations were completed. This allowed the analyst to focus on classifying calls from a subset of possible species/species groups. Separate processing for marine mammal groups allowed for better resolution in detection for all possible vocalizing animals. Figure C-1 in Appendix C illustrates the workflow of acoustic data processing and indicates which species were the focus of each processing run. The frequency range for each "run" was selected to review for the acoustic events for middle, low, and very low frequencies. Additional detail on methodology can be found in Appendix C.

Using these tools, the temporal distribution of marine mammal acoustic events was summarized, and data associated with call frequency and parameters were extracted from PAMGuard using PAMpal, an R package developed by Taiki Sakai to extract information from PAMGuard database and binary files (v0.13.0; Sakai 2020).

Once marine mammal call data were derived using the methods delineated above, these data were used to investigate the ability to successfully evaluate other ancillary analyses. For example, an evaluation of the location of vocalizing marine mammals was undertaken as well as an evaluation of marine mammal behavioral responses to noise; documentation of anthropogenic noise occurring during marine mammal acoustic events was logged; and an investigation of the Study soundscape ecology and Tetra Tech's novel evaluation of acoustic indices was conducted. These first sets of analyses were followed by a supplementary analysis on deep learning methods for detection and classification of marine mammal calls.

To evaluate anthropogenic noise, data were noted for passing ships, echosounders, platform noise, noise associated with adjacent moorings, and conductor cutting noise. Conductor cutting noise was first identified using an automatic detection algorithm using the source spectrum. The cutting event identified was then verified by comparing the event time to the cutting times provided by Freeport and additionally by OSA cutting times provided during the data analysis, and then confirmed by Tetra Tech both aurally and visually by the spectrum. The cutting noise was the dominant noise identified during the cutting period with the exception of the Freeport vessel (which is discussed in Section 4, Results). For the purposes of this effort, only ships that were close to the analyzed hydrophone were documented. Echosounders (e.g., sonar devices used on many ships to detect bottom depth) were recorded during this Study from passing ships. These brief pulses were detected by the PAMGuard software Automated Processing Mode utility known as called the "whistle and moan detector". Ship echosounder outputs have a distinct visible spectrogram shape both when approaching and leaving the area where recorders are deployed and were easily identifiable. Periods of conductor cutting that were clearly visible in the spectrogram were marked by documenting the start and end time. Conductor-cutting noise was compared to the provided operations cutting sheet time stamps that documented known periods of cutting, and any discrepancies or additional cutting noise above what was reported were noted.

Soundscape ecology is a relatively new field that examines acoustic relationships between organisms and their environment. The study of soundscape ecology is increasingly used as a tool for evaluating biodiversity and anthropogenic noise that insonifies an environment, as described in Pijanowski et al. (2011). That study characterized sound produced by biological organisms as biophony and anthropogenic sources of sound as anthrophony. This field is at the early stages of being used for monitoring marine environments (Bertucci et al. 2016; Bohnenstiehl et al. 2018; Erbe et al. 2015, Haver et al. 2018; Parks et al. 2014), having previously been used in terrestrial environments. The soundscape ecology for this Study was characterized using the acoustic indices ACI, BI, and NDSI.

3.4.3 Development of a Deep Neural Network for Humpback Whales and Delphinids

As part of this study of marine mammal species that may have been present during Study activities, a supplemental investigation was undertaken on deep learning methods of detection and classification (also known as deep neural networks). Large acoustic datasets in noisy environments can be time-consuming and labor intensive to review. Extensive anthropogenic noise can also confound the confirmation of calls from marine mammal species, requiring the participation of expert analysts to review the acoustic data in order to accurately identify species' calls. The objective of this effort was to develop a deep neural network and assess if it can be utilized to reduce the time and labor typically involved in these kinds of acoustic dataset reviews. This network was designed for successfully detecting marine mammal sounds of interest and reducing detection of noise within a large passive acoustic dataset. The goal was to provide a scalable deep neural network that can be used easily for future analyses.

Deep learning methods of detection and classification are increasingly considered valuable tools within the underwater acoustic community (Allen et al. 2021; Shiu et al. 2020; Vickers et al. 2021). Automation in recent years has improved signal processing, pattern recognition, and machine learning techniques for detection and classification of marine mammal sounds. Deep learning models are a form of machine learning that applies different filter banks at different scales and determines features used to discriminate signals during a learning stage (Bianco et al. 2019). The models are thus not reliant on meeting criteria for a series of target values, but rather independently determine important features using one of several neural networks. Two forms of common networks used in imagery recognition and classification are convolutional neural networks (CNN) and residual neural networks (Resnet). Several studies report high percentages of precision and recall as well as improved performance when testing involved multiple datasets collected in variable acoustic conditions (Kirsebom et al. 2020; Shiu et al. 2020). In addition to improved detection, deep neural networks offer capabilities in classifying marine mammal vocalizations, allowing for their use with multi-species analyses (Thomas et al. 2019).

To take advantage of these potential improvements through automation, a deep neural network was developed and evaluated using the dataset from this Study (Appendix D). The network was implemented in PAMGuard, and the performance of the deep neural network was evaluated in two ways: 1) by using diagnostic tools to evaluate how the network performs with a testing proportion of the annotated data, and 2) running the network on a different recorder likely to have detected the same marine mammals and consisting of different instrument noise conditions. The following subsections detail the development of this network.

3.4.3.1 Data Preparation

First, audio files were selected across multiple detections throughout the deployment. These files were reviewed to determine those with varying levels of call intensity for both humpback whales and delphinid species. The dataset was divided, with approximately 60 percent of the data subset selected for use in training and validation, and 40 percent for testing. This distribution is to avoid overtraining. The data were tested from the original recorder (5353) and an adjacent recorder (5356) to determine how well the network performed on detecting the same calls with different ambient sound.

During a 2019 workshop hosted by Marine Environmental Research Infrastructure for Data Integration and Application Network (MERIDIAN) and Ocean Networks Canada, developments in deep learning models were shared among the underwater acoustic communities (Frazao et al. 2020). As a result of this workshop, the well-documented software package Ketos was released providing users the capability of creating a deep neural network. The program highlights the use of a Resnet network, which has increased processing performance over CNNs. In a recent upgrade to PAMGuard (version 2.02.01), a deep learning module was incorporated that allows a user to import a neural network created in Ketos. Through integration of deep neural networks, an advanced detection and classification algorithm within the reliable, multi-faceted framework of PAMGuard is possible.

For all data used in training and validation, the software program Raven was used to annotate calls of interest and store those annotations in a selection table. After that step, the software packages described below were used to build a network. Selection tables were generated for both the burst pulse signals from delphinids and the low frequency moans from humpback whales. Selection tables were then formatted as per each software program.

3.4.3.2 Ketos/PAMGuard Network Development

Using Ketos, a Python-based program that incorporates the use of the TensorFlow machine learning platform, the Resnet model was selected for development of the networks. This was guided by the extensive instruction and training modules provided by MERIDIAN. Coordination was done with the software developers to work through differences and challenges in processing the Study data. Once the network was developed, it was tested in PAMGuard using a parameterized configuration file that included the deep neural network model.

3.4.3.3 DeepSqueak Network Development

DeepSqueak is a MATLAB-based, open access program that has been tested for use with MF to HF tonal calls. In 2019, Dr. Kevin Coffey of the University of Washington developed a MATLAB-based open access deep learning program called DeepSqueak (Coffey et al. 2019). While originally designed to detect and classify ultrasonic vocalizations from rats, Dr. Coffey focused on optimization of the network by reducing noise and incorporated a user-friendly graphical user interface (GUI) to allow any user to easily process and analyze acoustic signals of interest.

For this study, a version of DeepSqueak modified specifically for use with underwater acoustic data and originally parameterized to classify delphinid signals was employed. As this version had not previously been tested with either of the call types in the Study dataset, a neural network model was developed using the annotated selection tables.

The model was then trained iteratively within DeepSqueak through processing of detections within the framework and accepting true calls, rejecting noise, and further annotating any missed calls. This iterative process resulted in further training of the network to continually improve performance. Finally, a small dataset (ten hours of training data, six hours of testing data) was tested with the final network to determine its performance for calls on two recorders. Precision, recall, and an F-score were calculated for the testing datasets. The formulas below illustrate how precision, recall, and the F-score are calculated.

Precision is the ratio between the true positives and all of the positives and indicates how good the model is at detecting.

$$\text{Precision} = \frac{\text{True positives}}{\text{True positives + False positives}} = \frac{\text{Calls correctly detected}}{\text{Calls correctly detected + noise incorrectly detected as calls}} \tag{1}$$

Recall relates to the sensitivity of the model and indicates how correct it is at identifying true positives.

$$\text{Recall} = \frac{\text{True positives}}{\text{True positives + False negatives}} = \frac{\text{Calls correctly detected}}{\text{Calls correctly detected + calls not detected as calls}} \tag{2}$$

An F-score combines the precision and recall of a classifier into a single metric to compare different models.

$$\text{F1 score} = 2 * \frac{\text{Precision * recall}}{\text{Precision + recall}} \tag{3}$$

The F1 score reports a harmonic mean for detector performance that provides equal weight to both precision and recall as opposed to just conducting a simple average, which can be more influenced by outlying values. A classifier with a precision of 1 and recall of 0 has a simple average of 0.5 but an F1 score of "0." To create a classification model with the optimal balance of recall and precision, it is critical to maximize the F1 score.

Collectively, these values provide a means of evaluating detector performance. It should be noted that while a functional network was intended to be provided for this effort, the model was not exhaustively trained to perfect it. This decision was made largely because of the scope of this effort as well as the need to incorporate more variability in calls from additional datasets that would be analyzed using this detector.

4 Results

This section describes the results for the conductor-cutting sound analysis and findings from marine mammal calls acquired during the Study period.

4.1 Environmental Conditions

Wind and wave data were evaluated for the study period to determine if there were any significant events that would affect the acoustic data. Wave data were obtained from the Station 46218-Harvest, CA (071) buoy, which is part of NOAA's National Data Buoy Center and provides the significant wave height calculated as the average of the highest one-third of all of the wave heights during a 20-minute sampling period. Wind speed data were obtained from the Station 46054 (LLNR 198.1) – West Santa Barbara buoy, which provides wind speed data averaged over an 8-minute period. The location of these buoys in relation to the Study area is shown in Figure 11.

During the study period, the wind speed ranged from approximately 1.6 meters per second (m/s) to 16.7 m/s, with the peak occurring on April 10, 2021. The average wind speed for the Study period was 10 m/s. Wave heights during the study period ranged from approximately 1.2 to 3.8 m (4 to 12.5 ft), with the peak also occurring on April 10, 2021. The average wave height during the Study period was 2.3 m (7.5 ft). Figures 12 and 13 show the wind speed and wave height data for the entire study period. These figures show that there is a direct correlation between the increase in wind speed and the increase in wave heights. However, these data do not identify any significant events that would affect or significantly influence the acoustic data.

4.1.1 Measured Water Properties

The thermistor chain was deployed at approximately 464 m (1,522 ft) from the edge of Platform Hermosa at an approximate depth of 193 m (633 ft). The sensors on the thermistor chain collected measurements of temperature, and pressure at various depths throughout the water column. The measurements, together with the conductivity-temperature-depth sensor on the NoiseSpotter Platform, provide data necessary to calculate the sound speed profile over the duration of the study period. Figure 14 shows the mean temperature as a function of depth, along with time- and depth-dependent temperature as measured over the deployment duration. An approximately 1.5 degrees Celsius (°C) mean temperature gradient is observed, indicative of typical winter well-mixed waters with little stratification. Nonetheless, there appears to be more intense episodic warming and cooling of waters, whose timescales on the order of hours suggest internal wave activity, as has been previously observed in this region (Colosi et al. 2018).

Figure 15 shows the mean sound speed as a function of depth and time- and depth-dependent sound speed as measured over the deployment duration. Similar to temperature, mean sound speeds show little variability over the measurement period, ranging from 1,487 to 1,490 m/s. Nevertheless, smaller scale processes such as internal waves do appear to induce larger magnitude time and depth variability to the sound speed profiles, suggesting that any future acoustic propagation modeling should take this temporal and depth variability into account.

The temperature and speed of sound profile data were then averaged for the 21-day study period. These data were used as an input to the sound propagation model.

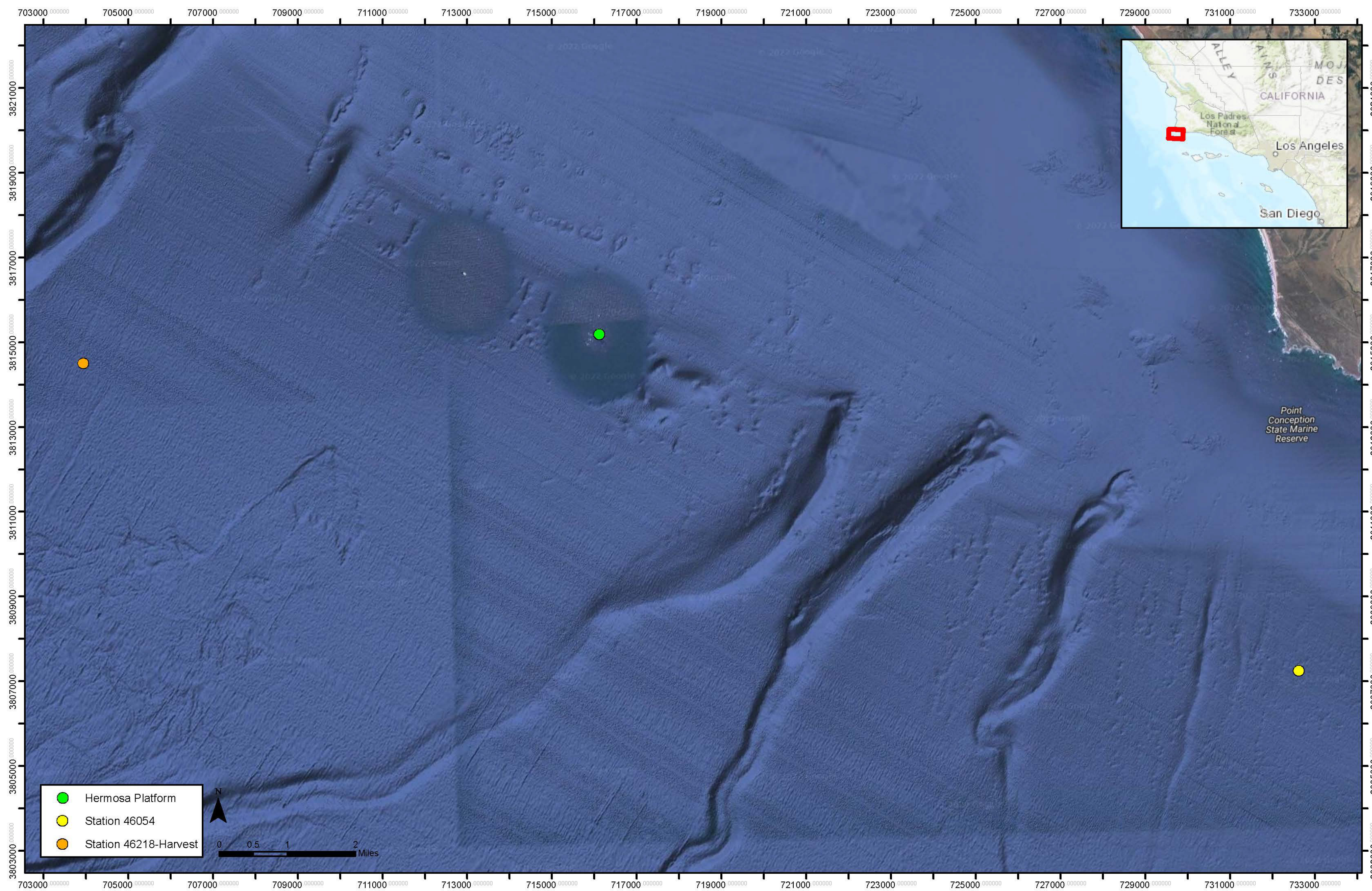


Figure 11. Location of Weather Buoys

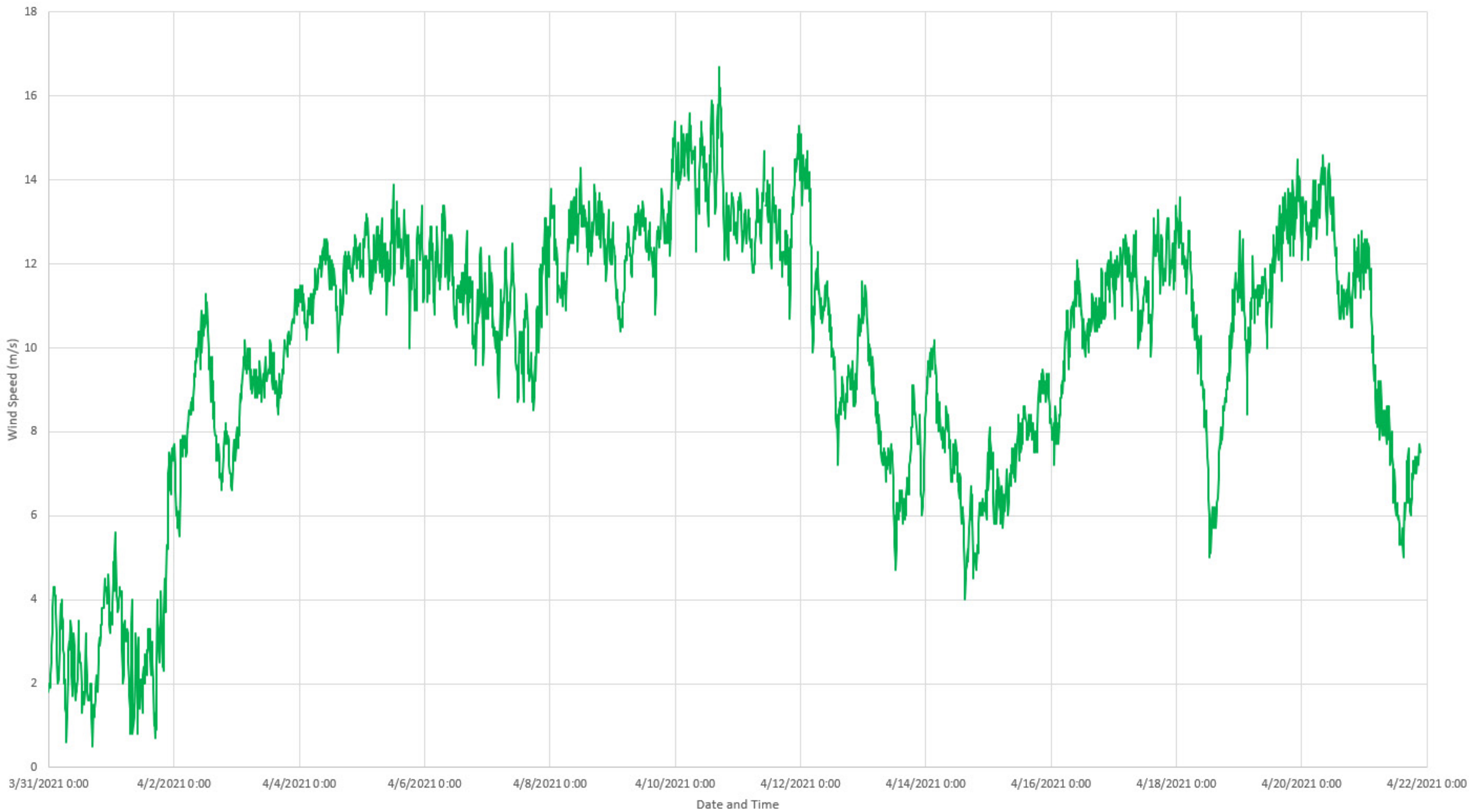


Figure 12. Wind Speed Data for the Study Period

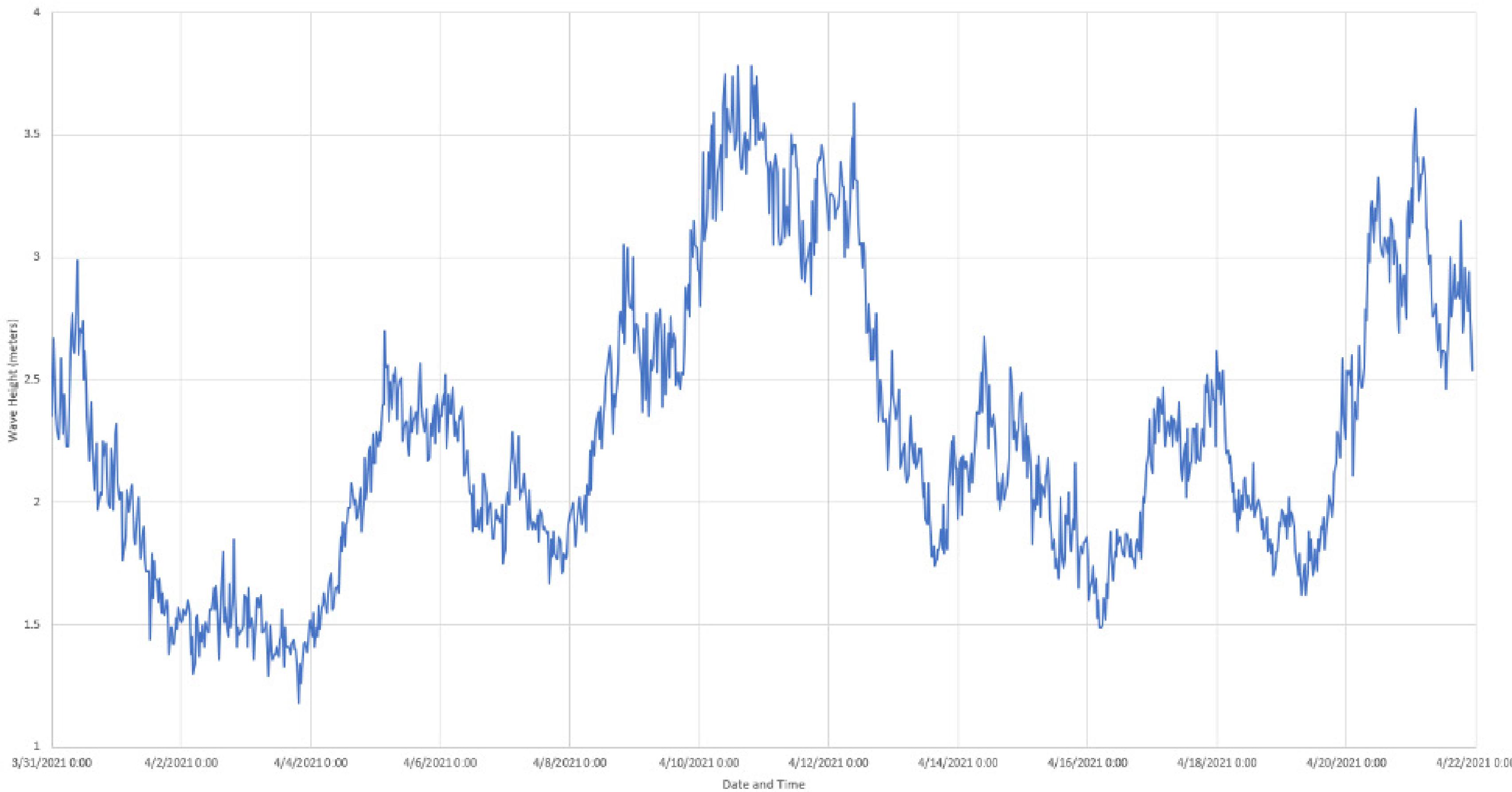


Figure 13. Wave Height Data for the Study Period

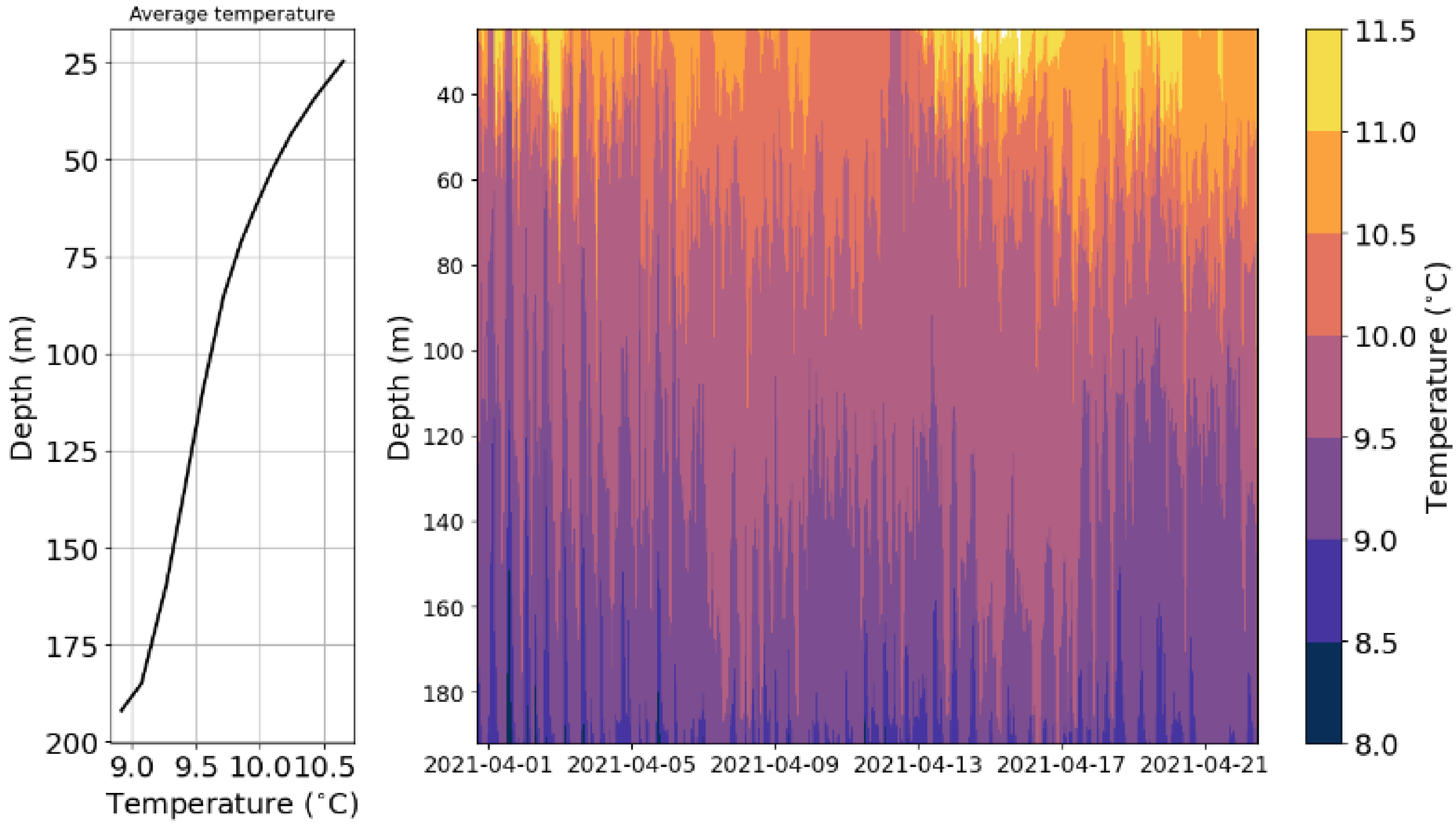


Figure 14. Mean Temperature and Time- and Depth-Dependent Temperature over the Deployment Period

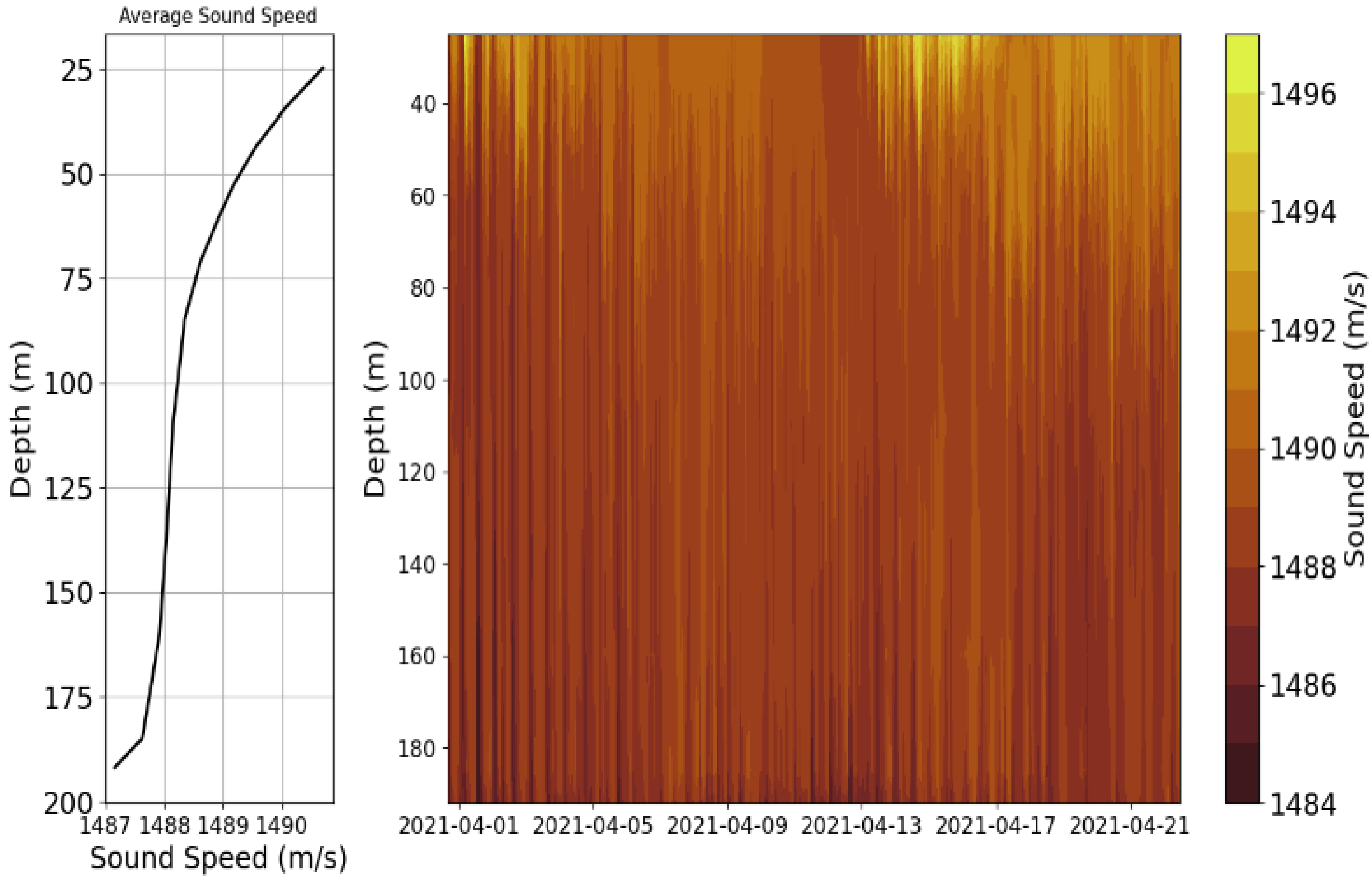


Figure 15. Mean Sound Speed and Time- and Depth-Dependent Sound Speed over the Deployment Period

4.1.2 Ambient Noise Levels

Ambient noise in the ocean is generated by physical (e.g., waves, wind, rain, tectonic activity) and biological (e.g., snapping shrimp and fish sounds, marine mammal vocalizations) processes, as well as man-made sources, such as vessel traffic. There can be a strong minute-to-minute, hour-to-hour, or seasonal variability in sounds from biological sources. In general, the ambient noise for frequencies above 1 kHz is due largely to waves, wind, and heavy precipitation (Simmonds et al. 2004). Ambient noise levels for frequencies below 1 kHz are more often associated with biological and anthropogenic sound sources such as vessels. Surface wave interaction and breaking waves with spray have been identified as significant sources of noise. Wind-induced bubble oscillations and cavitation are also near-surface noise sources. Major storms can give rise to noise in the 10 to 50 kHz frequency band, which can propagate over long distances using the same mechanism and directionality as distant vessels. At areas within distances of 8 to 10 km (5.0 to 6.2 mi) of the shoreline, surf noise will be prominent in the frequencies ranging up to a few hundred Hz (Richardson et al. 2013).

During the deployment and retrieval of the monitoring equipment, vessels within the shipping lane located approximately 6.8 km (4.2 mi) south of Platform Hermosa were visually identified. The vessel traffic density in the vicinity of the Study area and the vessel routes are shown in Figure 16.

Continuous ambient data were not able to be collected prior to the start of the mechanical cutting or after completion of the cutting due to the overall mechanical cutting duration at Platform Hermosa and logistics. However, there was a single, approximately 29-hour period during which mechanical cutting did not occur and no platform associated vessel activity was observed within the Study area. This period occurred from 17:00 on April 9, 2021 to 00:30 on April 11, 2021. No significant events were identified during this period; however, noise generated from the platform was identified. The dominant noise from the platform was associated with generators and operations of the platform. Therefore, noise at the farthest measurement location (SoundTrap 5353) is shown to result in lower ambient noise levels compared to the closer measurement locations. Furthermore, the mid-water column measurement location (SoundTrap 5363) resulted in higher ambient noise levels, which shows influence from surface equipment such as generators as well as noise from wave action. The ambient noise levels measured for this approximately 29 hour period are summarized in Table 5.

Table 5. Ambient Data Summary

Ambient Period		Monitor Station Name	Distance to Platform (m)	L_p	Max L_p	Min L_p	$L_{p,pk}$	L_E
Start Time	End Time							
4/9/2021 17:00	4/11/2021 0:30	5362	101	114.0	129.3	108.8	149.3	164.2
		5363	101	115.7	127.0	110.2	152.3	165.9
		5366	98	114.5	126.9	107.2	154.1	164.8
		5365	100	114.5	126.4	108.0	148.9	164.7
		5356	92	114.5	125.0	109.5	146.1	164.8
		5353	252	111.5	122.0	106.6	151.1	161.8

Note: Data presented in this table are processed using a 1-second interval.
Data provide in this table is based on a duration of 1,770 minutes.
The maximum level is the highest-level record for each measurement location over the total duration.
The minimum level is the lowest level record for each measurement location over the total duration.
L_p and $L_{p,pk}$= (dB re 1 μPa); L_E = (dB re 1 μPa^2·s)

Figure 17 shows the time history of ambient noise levels described in Table 5 using the 1-second interval averaging periods. However, due to the high number of data points, the time history plot does not clearly show the noise trend at and away from the platform.

The average ambient noise levels within the vicinity of the study area ranged from 114 dB SPL to 116 dB SPL at an approximate distance of 100 m (328 ft) from the edge of the platform. The ambient noise levels near the platform resulted in higher noise levels because during this period the dominant noise was generated from the platform operations. The ambient sound level at 250 m (820 ft) from the platform edge was 112 dB SPL. The underwater acoustic environment within the Study area is directly affected by the daily operations of Platform Hermosa not associated with actual conductor cutting. To show this trend more clearly, the time history data were resampled using a 1-minute sampling interval. Using a higher averaging interval separates the data more to show the identified trend in ambient sound levels, but the averaging reduces the highest levels due to the increased sampling period. Figure 18 clearly shows the influence from the typical platform operations not associated with actual conductor cutting on the ambient noise levels near the platform and that this influence is reduced at greater distances from the platform.

4.2 Well and Conductor Cutting Events

Data were collected for the mechanical cutting events for a total of 21 days from April 1, 2021 to April 21, 2021. Abrasive cutting was not conducted in the course of this study. During this period, a total of 25 wells and empty conductors were cut over 40 identified cutting events. The cut depth ranged from 6 m to 8 m (20 ft to 25 ft) below the mudline and the cutter revolutions per minute (RPM) ranged from 60 to 72 RPM. The duration of the cuts was dependent on the number of casing strings that needed to be cut. Wellbores that contained more casing strings took much longer to cut compared to the empty conductors (see Figure 19). In total, 9 wellbores and 16 empty conductors were cut during the monitoring period. Table 6 provides a summary of the mechanical cutting events, and Figure 20 shows the conductors that were cut during the monitoring period.

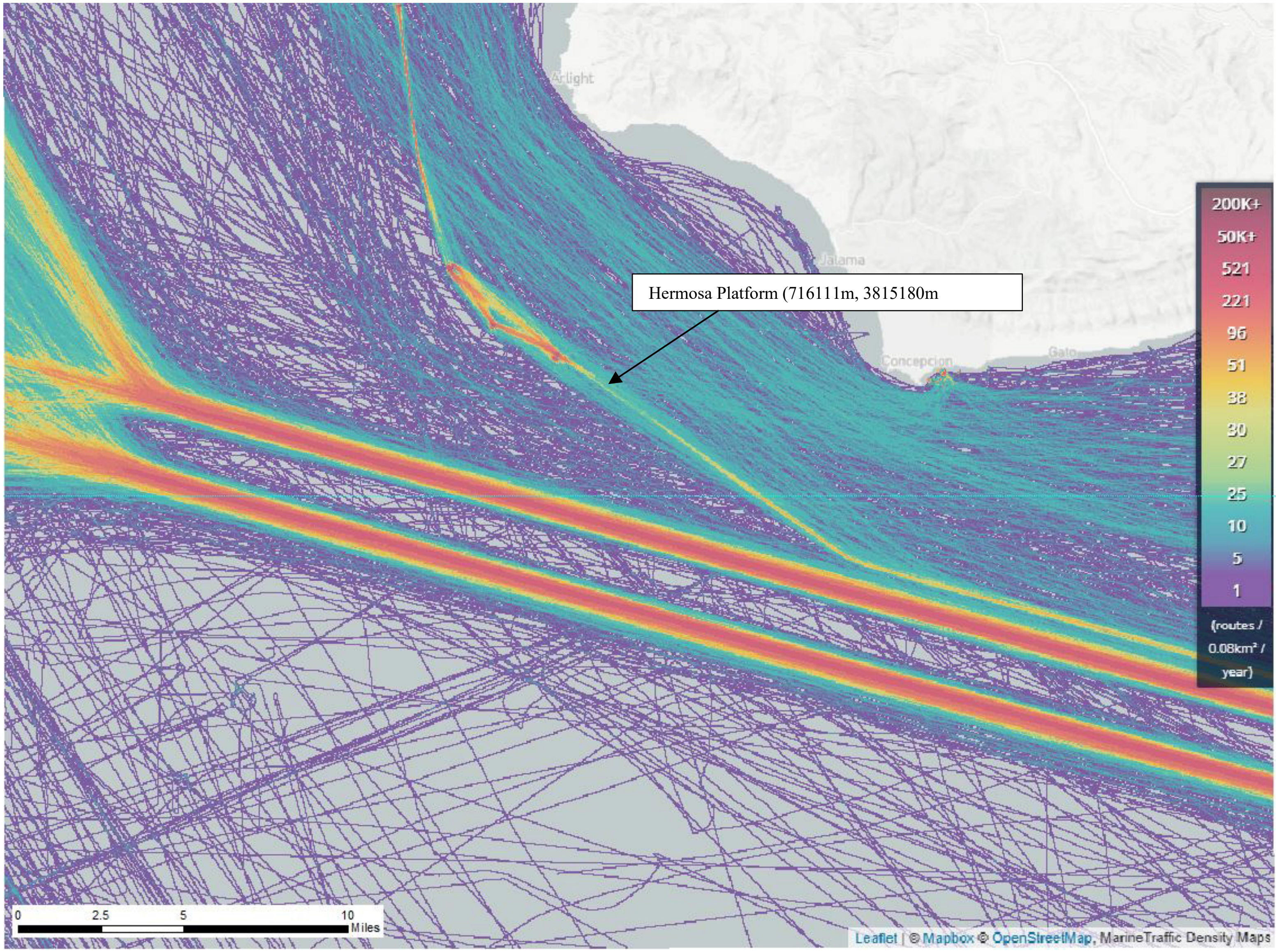


Figure 16. Vessel Routes in the Vicinity of the Study Area (Marine Traffic 2022)

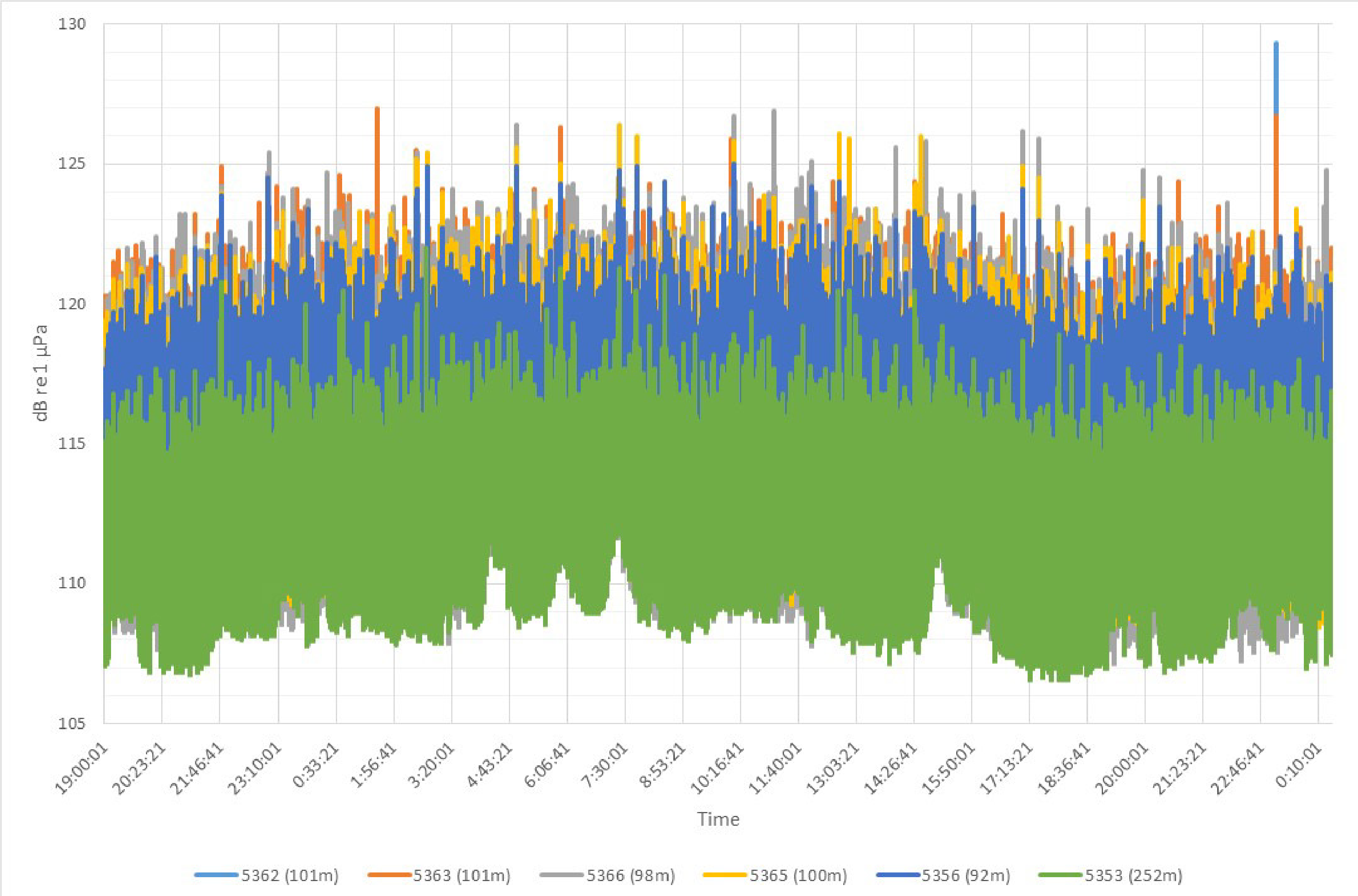


Figure 17. Ambient Noise Levels (1-second sample interval)

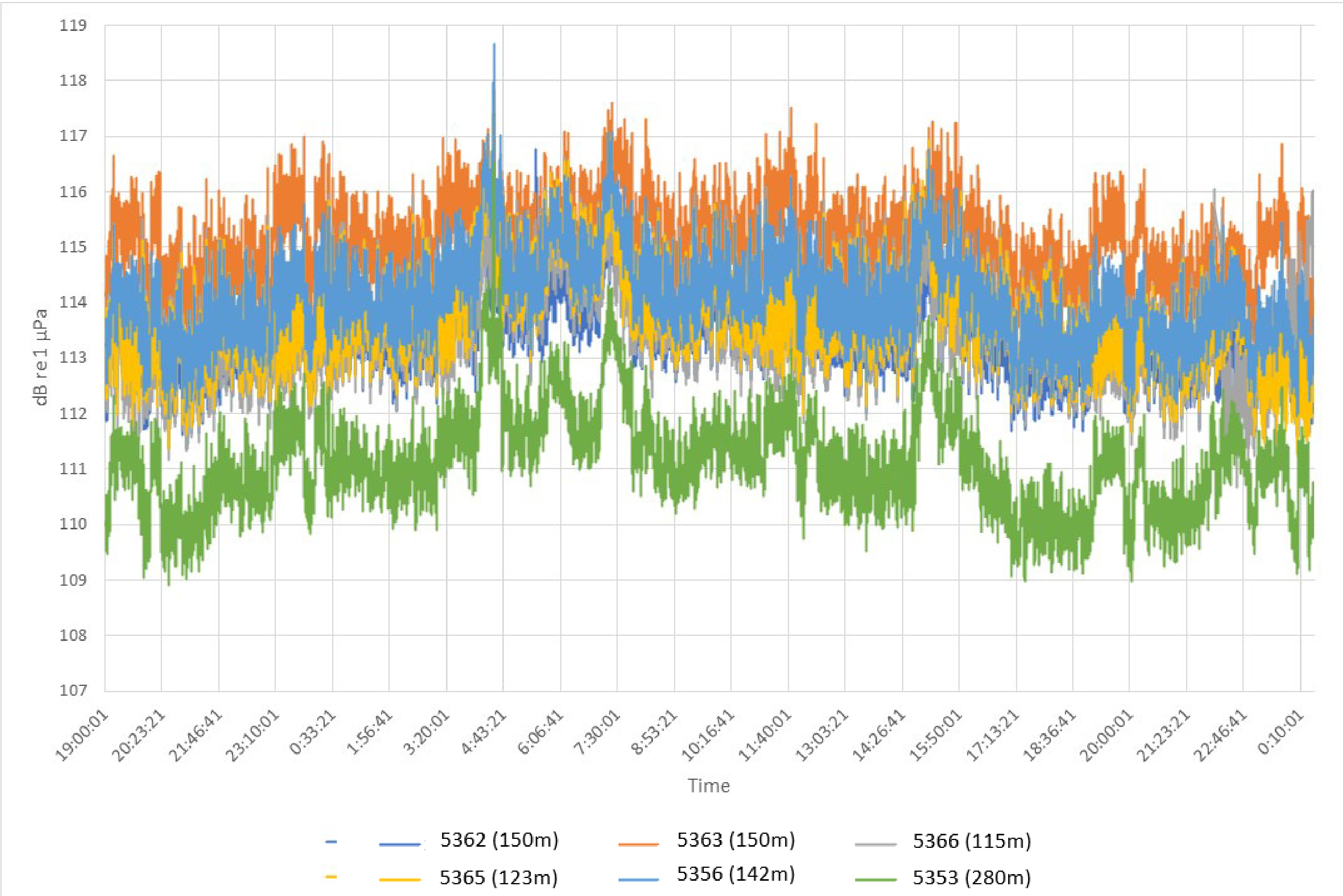


Figure 18. Ambient Sound Levels (1-minute sample interval)

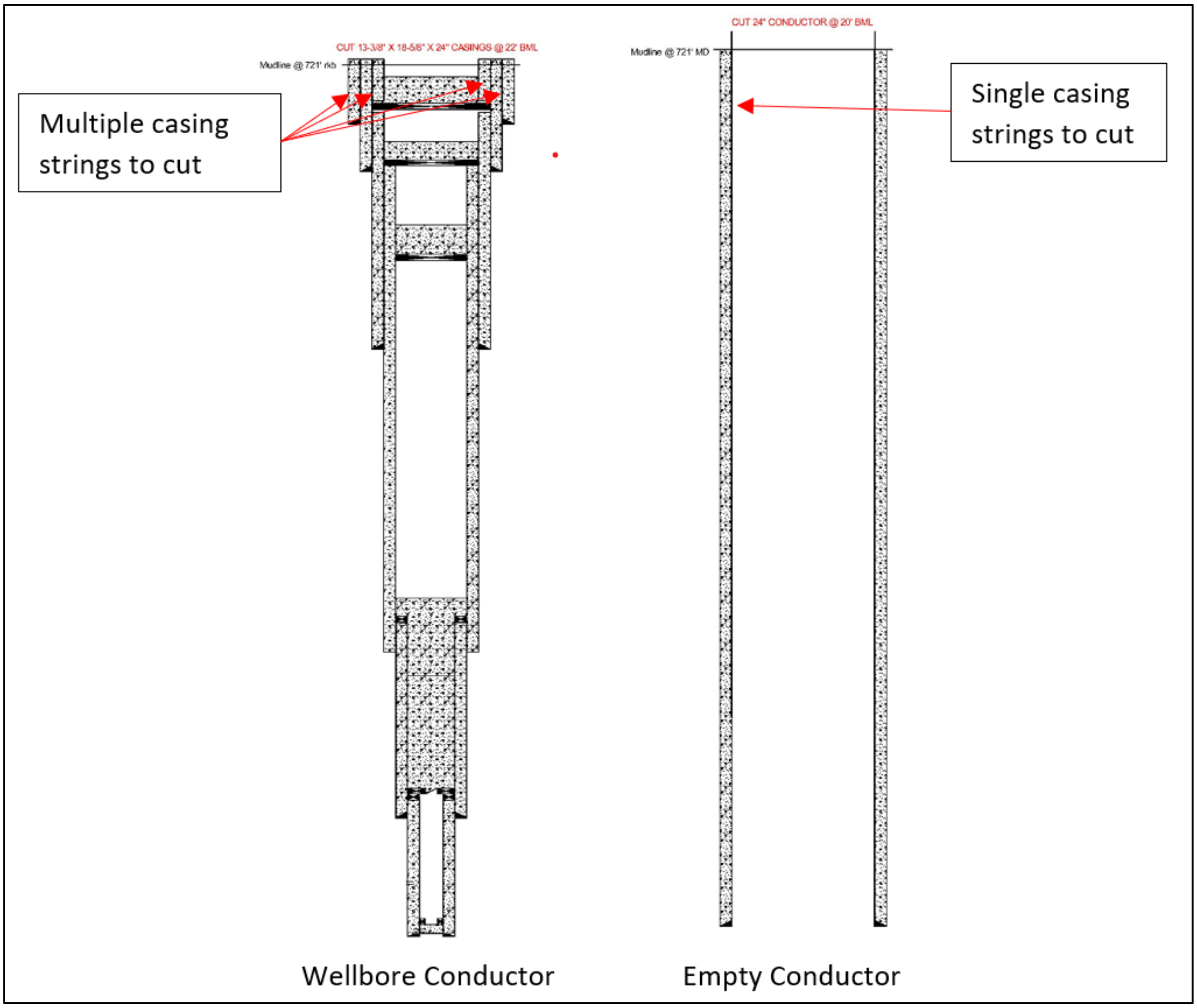


Figure 19. Example of Wellbore and Empty Conductor

Table 6. Mechanical Cutting Events Summary
The overall wall thickness, in inches, can comprise multiple casing strings within a wellbore. Wells are denoted with the prefix ‘B’ and empty conductors are denoted with the prefix ‘S’.

Conductor	Start Time	End Time	Total Duration of Cut (minutes)	Number of Casing Strings and Overall Diameter (inches)	Overall Wall Thickness (inches)	Cut Depth Below Mudline (Feet)	Cutter RPM
B-1	4/1/2021 17:06	4/1/2021 17:25	16	String 1 – 13-3/8” String 2 – 18-5/8” String 3 – 24”	1.857	25	60
	4/1/2021 18:01	4/1/2021 18:54	53				
	4/1/2021 22:05	4/2/2021 4:08	363				
B-9	4/2/2021 17:42	4/2/2021 19:18	96	String 1 – 9-5/8” String 2 -13-3/8” String 3 – 18-5/8” String 4 – 24”	1.542	22	68
	4/2/2021 23:37	4/3/2021 6:28	411				
	4/3/2021 15:35	4/3/2021 21:42	367				
B-16	4/4/2021 14:19	4/4/2021 16:37	138	String 1 – 13-3/8” String 2 – 18-5/8” String 3 – 24”	1.919	25	72
	4/4/2021 19:00	4/5/2021 8:03	783				
	4/5/2021 11:58	4/5/2021 23:32	694				
B-3	4/6/2021 8:00	4/6/2021 9:36	96	String 1 – 13-3/8” String 2 – 18-5/8” String 3 – 24”	1.919	20	60
	4/6/2021 13:02	4/6/2021 15:33	151				
S-25	4/7/2021 9:51	4/7/2021 10:53	62	24”	0.812	20	60
S-29	4/7/2021 18:35	4/7/2021 19:17	42	24”	0.812	20	60
S-33	4/8/2021 4:06	4/8/2021 5:44	98	24”	0.812	20	60
S-46	4/8/2021 12:49	4/8/2021 15:45	176	24”	0.812	20	60
S-47	4/9/2021 0:20	4/9/2021 1:43	83	24”	0.812	20	60
S-36	4/9/2021 7:08	4/9/2021 7:59	51	24”	0.812	20	60
S-34	4/9/2021 15:07	4/9/2021 16:45	98	24”	0.812	20	60
B-17	4/10/2021 22:41	4/11/2021 1:10	149	String 1 – 13-3/8” String 2 – 18-5/8” String 3 – 24”	1.919	20	60
	4/11/2021 4:40	4/11/2021 15:51	671				
S-41	4/11/2021 21:06	4/11/2021 23:00	114	24”	0.812	20	60
S-28	4/12/2021 9:48	4/12/2021 15:35	347	24”	0.812	20	60
S-12	4/13/2021 11:50	4/13/2021 12:47	57	24”	0.812	20	60
S-23	4/13/2021 21:05	4/13/2021 22:29	84	24”	0.812	20	60
S-21	4/14/2021 7:44	4/14/2021 10:48	184	24”	0.812	20	60

Conductor	Start Time	End Time	Total Duration of Cut (minutes)	Number of Casing Strings and Overall Diameter (inches)	Overall Wall Thickness (inches)	Cut Depth Below Mudline (Feet)	Cutter RPM
B-14	4/14/2021 17:06	4/14/2021 19:05	119	String 1 – 13-3/8” String 2 – 18-5/8” String 3 – 24”	1.919	20	60
	4/15/2021 1:05	4/15/2021 10:59	599				
S-9	4/15/2021 18:23	4/15/2021 20:01	98	24”	0.812	20	60
B-08	4/16/2021 8:33	4/16/2021 10:21	108	String 1 – 13-3/8” String 2 – 18-5/8” String 3 – 24”	1.919	20	60
	4/16/2021 13:07	4/16/2021 18:32	325				
B-13	4/17/2021 1:54	4/17/2021 3:41	107	String 1 – 9-5/8” String 2 -13-3/8” String 3 – 18-5/8” String 4 – 24”	2.354	20	60
	4/17/2021 7:02	4/17/2021 15:48	526				
	4/17/2021 17:09	4/18/2021 3:56	647				
B-10	4/18/2021 12:47	4/18/2021 14:30	103	String 1 – 13-3/8” String 2 – 18-5/8” String 3 – 24”	1.919	20	60
	4/18/2021 15:58	4/18/2021 17:17	79				
	4/18/2021 21:06	4/18/2021 23:02	116				
	4/18/2021 23:22	4/19/2021 1:52	150				
S-7	4/19/2021 7:41	4/19/2021 10:20	159	24”	0.812	20	60
S-6	4/19/2021 15:47	4/19/2021 23:37	470	24”	0.812	20	60
S-4	4/20/2021 11:30	4/20/2021 12:55	85	24”	0.812	20	60

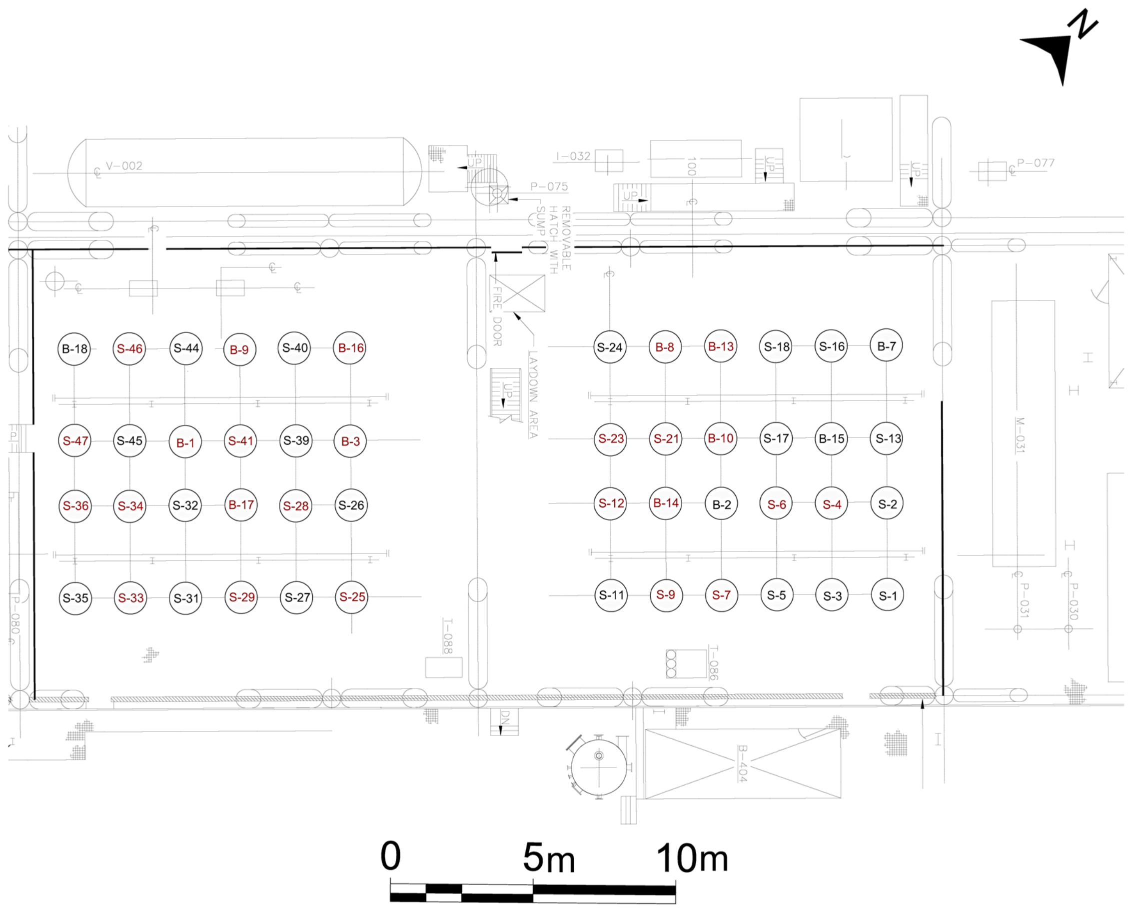


Figure 20. Conductors Cut During Monitoring Operation (Red)

4.3 Mechanical Cutting Events Sound Data Summary

Table B-1 in Appendix B provides a summary of the measured sound levels from each of the mechanical cutting operations measured during the study period.

Figure 21 shows all of the cutting events in a PSD spectrogram. This spectrogram was generated from SoundTrap 5353 located approximately 252 m (827 ft) from the platform.

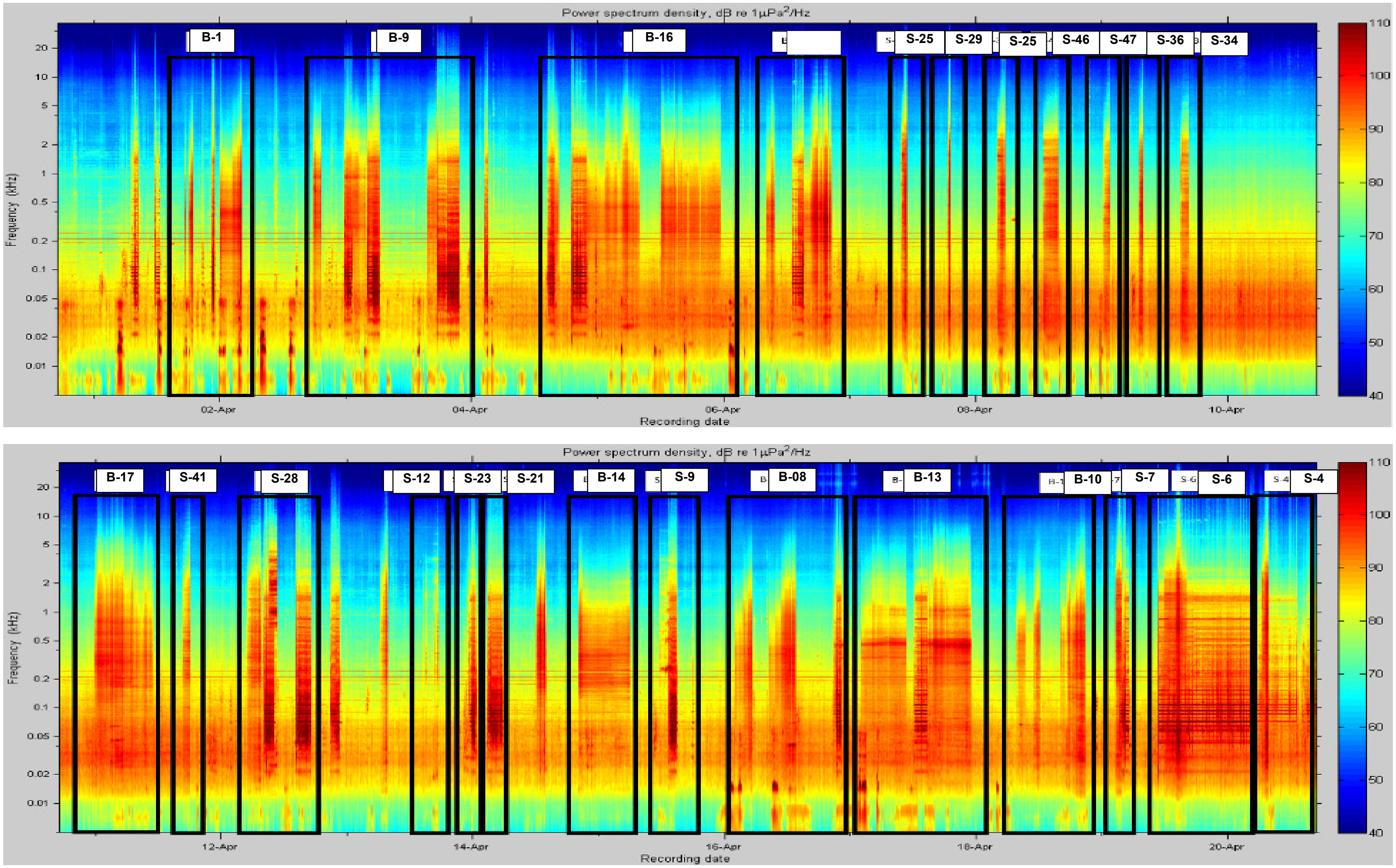


Figure 21. Long-Term PSD Spectrogram Showing All Cutting Events (SoundTrap 5353)

4.3.1 Acoustical Analysis of the Mechanical Cutting Events

A total of 25 wells and empty conductors were cut with 40 identified cutting events. Table B-1 in Appendix B provides a summary of the measured sound level from each of the mechanical cutting event measured during the study period. Appendix B also provides measurement results for each individual cutting event.

Nine wellbore conductors were monitored over the Study period. The wellbore conductors contain multiple casing strings, which required two to four cuts per wellbore, and the overall cutting time ranged from 4 hours to 27 hours. The monitor located closest to the wellbore was SoundTrap 5366 and the distance of SoundTrap 5366 relative to the wellbore ranged from approximately 106 m to 117 m (348 to 384 ft) depending on the specific conductor being cut. At SoundTrap 5366, the measured sound levels ranged from 120 to 130 dB SPL. The monitor located furthest from the wellbore was SoundTrap 5353, which was positioned at a distance ranging from 275 to 293 m and resulted in measured sound levels ranging from 114 to 124 dB SPL depending on the conductor being cut. The measured frequency spectrum of the wellbore cuts shows influence from the cutting operations from 25 to 10,000 Hz with a significant influence from 125 to 2,000 Hz. As an example, Figure 21 shows the 1/3 octave band spectrum for all of the wellbore cuts at the nearest measurement location (SoundTrap 5366).

The majority of wellbore conductors were cut at a depth of 6 m (20 ft) below the mudline. Wellbore conductors B-1, B-9, and B-16 were cut at slight deeper depths of 22 to 25 ft below the mudline. Comparing these three wellbore conductors to the other six, the cutting depth does not appear to have a noticeable influence on the overall measured sound levels and spectrum. However, the variation in cutting depth is 5 ft or less and greater differences in cutting depths could result in a noticeable change. Additional data would be required to evaluate the influence from cutting depth. Wellbore conductors B-9 and B-16 were the only conductors cut at a higher rate than 60 RPM; B-9 was cut using a higher RPM of 68 and B-16 used an RPM of 72. This change in RPM did not result in a noticeable difference to the sound levels or spectrum. Therefore, due to the limited amount of data collected during cutting at different RPM rates, no conclusions or trends can be identified by changing the RPM.

Sixteen empty conductors were monitored over the Study period. The empty conductors only required the outer casing to be cut, which resulted in much lower cutting times ranging from 0.7 hours to 8 hours. The monitor located closest (SoundTrap 5366) to the empty conductors ranged from approximately 103 to 119 m (338 to 390 ft). At the closest location the sound levels ranged from 118 to 133 dB SPL. The monitor positioned farthest (SoundTrap 5353) from the empty conductors ranged from 271 to 298 m (889 to 978 ft) with sound levels ranging from 111 to 125 dB SPL. Similar to the wellbore cuts, the frequency spectrum of the empty conductor cuts shows influence from the cutting operations from 25 to 10,000 Hz. However, the significant influence extended a broader frequency range from 32 Hz to 5,000 Hz. Figure 22 shows the 1/3 octave band spectrum for all of the wellbore cuts at the nearest measurement location. The difference in the frequency range between the empty conductors and the wellbore conductors is likely due to the multiple casing strings within the wellbore conductors allowing less acoustic propagation.

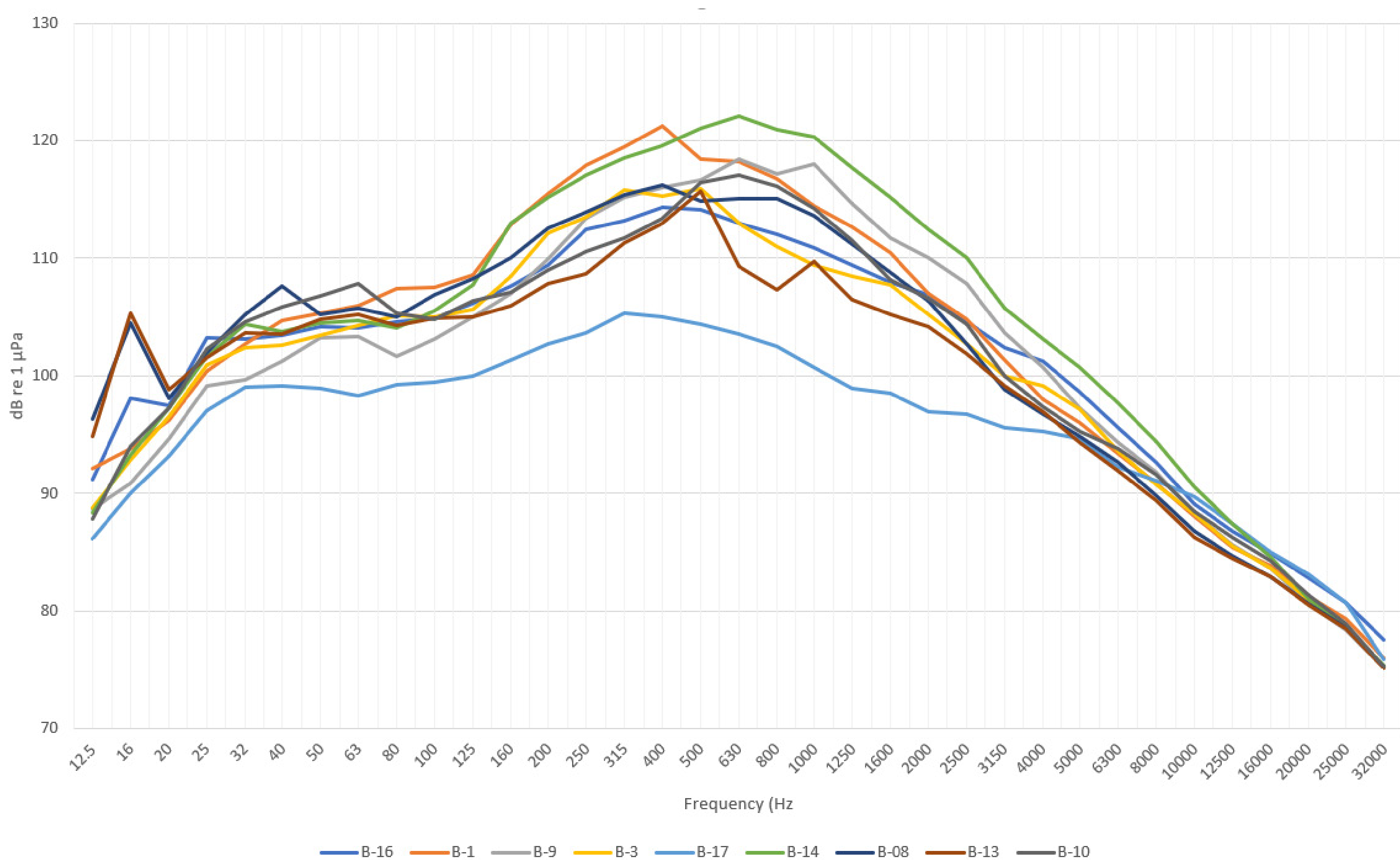


Figure 22. SPL 1/3 Octave Band Plot for All Wellbore Cut (SoundTrap 5366)

Evaluating the measured sound levels at the mid-water column monitor helps to further describe how the cutting events radiate sound within the water column. For all wellbore and empty conductor cutting events the mid-water column (SoundTrap 5363) resulted in similar or slightly higher measured sound levels than the monitor on the same mooring positioned at the bottom of the water column (SoundTrap 5362). This demonstrates that sound is not only generated at the cutting locations, beneath the mudline, but also up through the length of the conductor. For example, Figure 23 shows the time history plot of the mechanical cut for the empty conductor S-29. This plot shows the similar measured sound levels throughout the duration of the cut at the measurement locations at mid-water column depth (SoundTrap 5363) and at the bottom of the water column (SoundTrap 5362). Figure 23 also shows the sound levels from the cutting operations increase over the duration of the cut where there are higher sound levels at the end of the cut. This trend was identified for the majority of the empty conductor cuts. Figure 24 further illustrates this trend for the S-4 empty conductor cut where the sound levels increase over the duration of the event. However, this trend was not clearly identified for the wellbore cutting events.

The sound generated by the cutting operations significantly increased the ambient sound levels in the vicinity of the platform. The wellbore cutting operations resulted in a 14 dB to 27 dB increase over the existing noise levels and the empty conductor cuts resulted in an increase of 18 dB to 33 dB over the existing noise levels.

4.3.2 Vessel Noise Influence on Conductor Cutting Measurements

In support of the conductor cutting operations, the Motor Vessel (M/V) *Harvey Challenger* (Freeport's dynamically positioned supply vessel) was present for approximately 25 percent of the cutting events. The vessel indirectly supported the cutting operations by moving equipment and supplies. During the first and second cuts for B-16 wellbore, it was documented that the M/V *Harvey Challenger* was present during the initial cutting operations. The first cut occurred for approximately 138 minutes (April 4, 2021, 14:19 to 16:37) and the second cut occurred for approximately 783 minutes (April 4, 2021, 19:00 to April 5, 2021, 8:03). At the start of both cuts, the vessel was located at the east crane. As shown in Figures 25 and 26**,** the vessel and cutting operations directly overlap for the majority of the cutting period for the first cut, where the vessel is the dominate sound source. Figures 27 and 28 show the vessel at the start of the second cut. These figures clearly show that when present the vessel noise is the dominate source over the cutting operations.

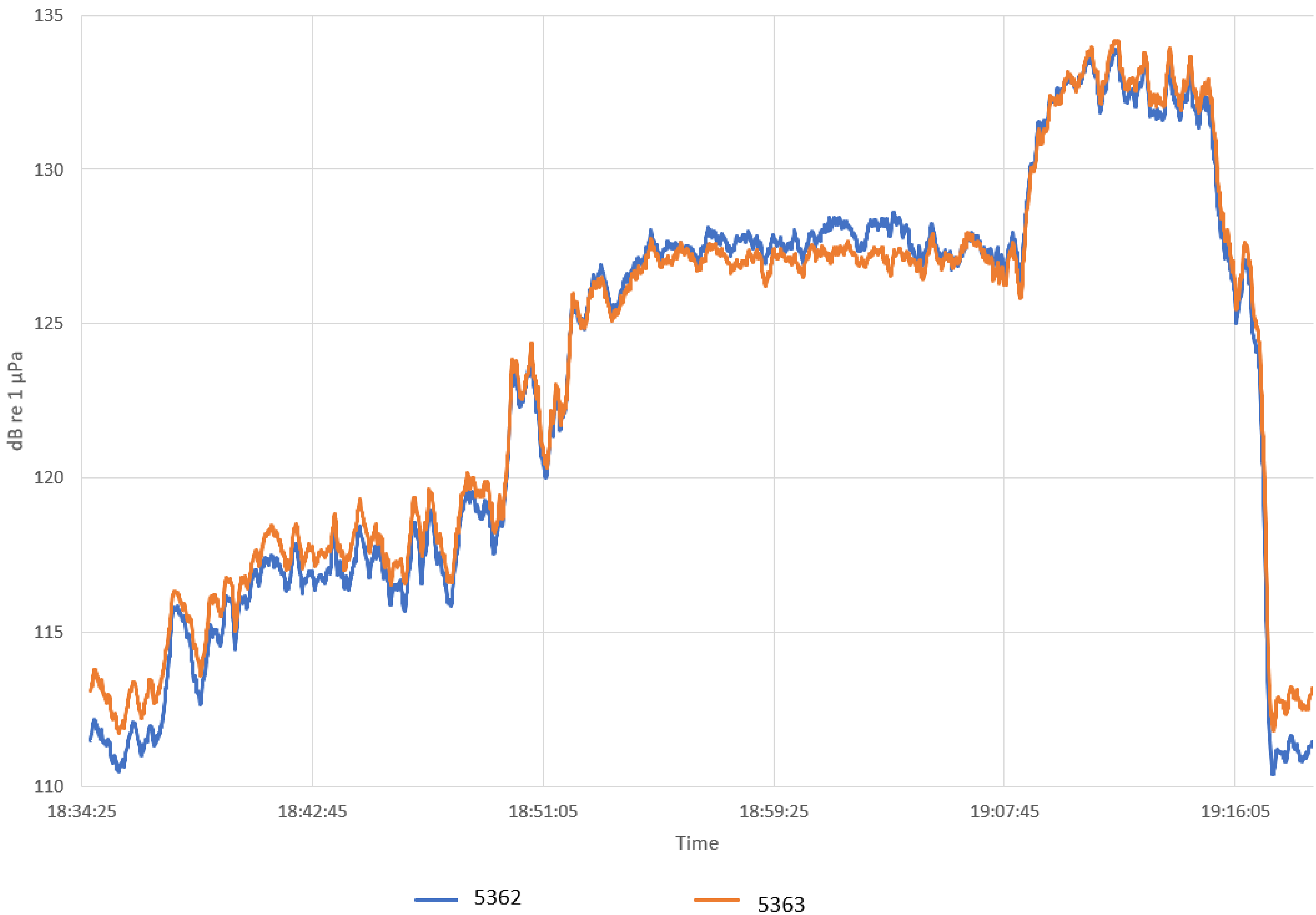


Figure 23. Time History Plot of S-29 Mechanical Cut at Mid-water (5363) and Bottom (5362)

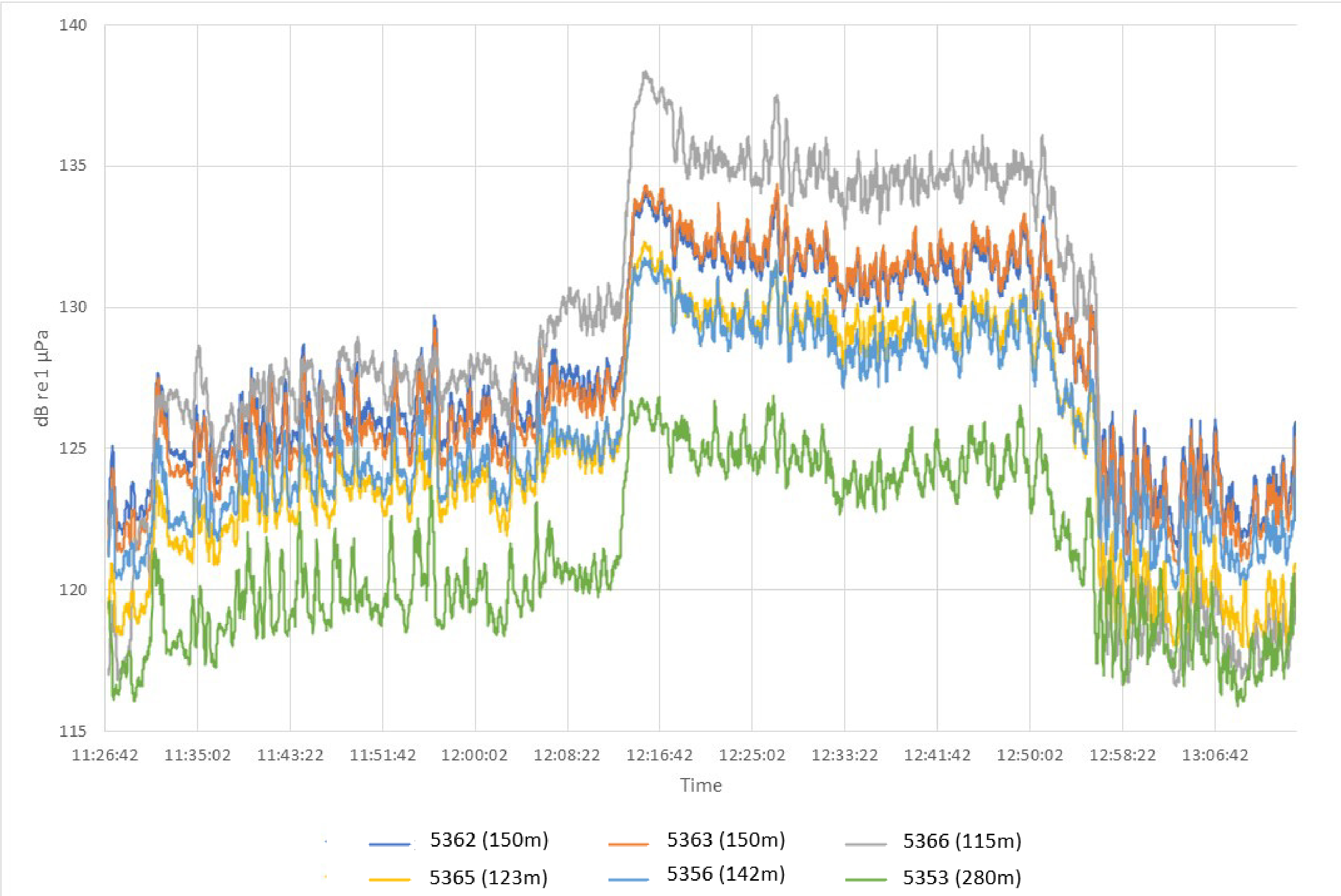


Figure 24. Time History Plot of S-4 Mechanical Cut from April 20, 2021, 11:30 to 12:55 (20-second sample interval)

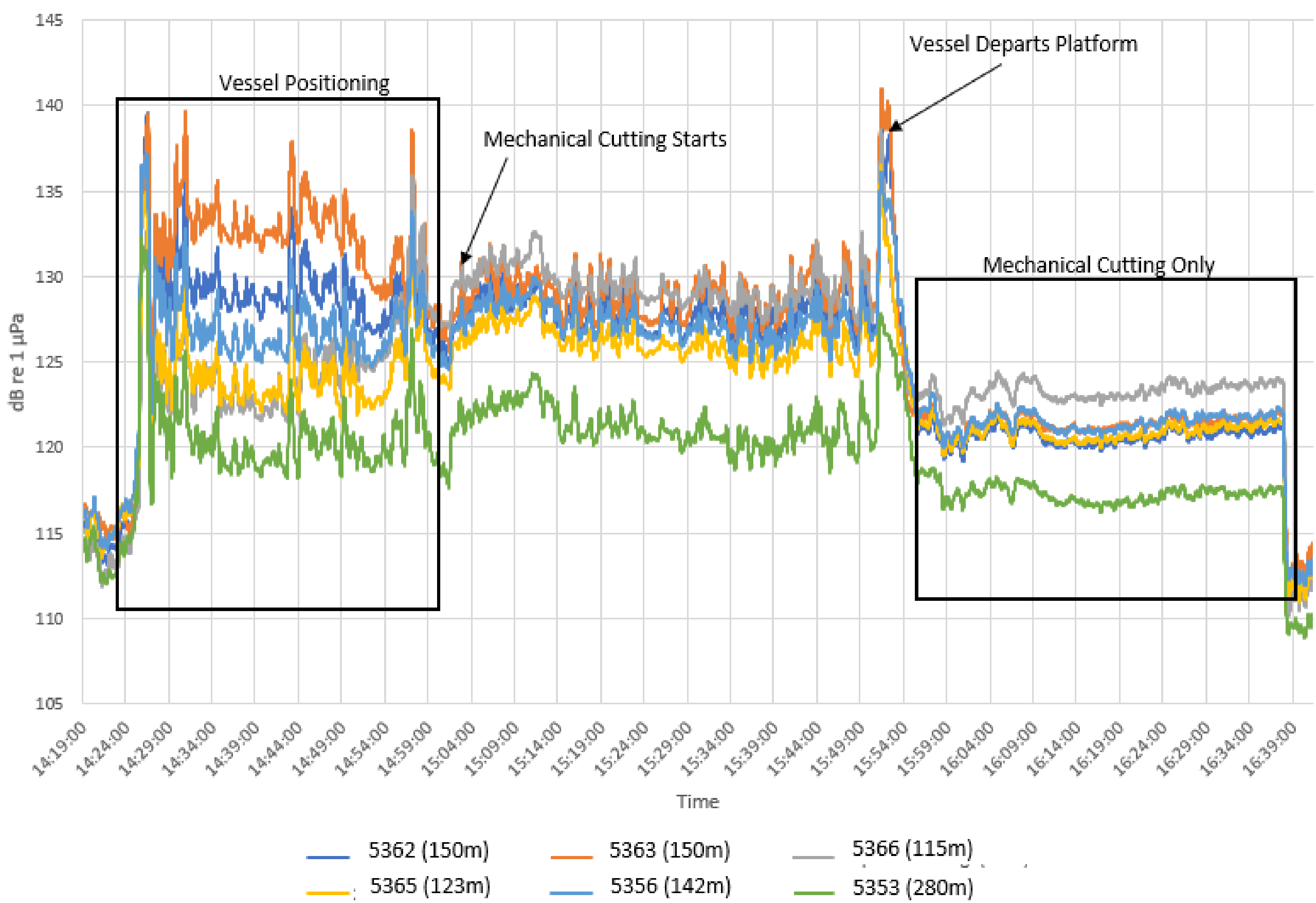


Figure 25. Time History Plot of B-16 Mechanical Cut from April 4, 2021, 14:19 to 16:37 (20-second sample interval)

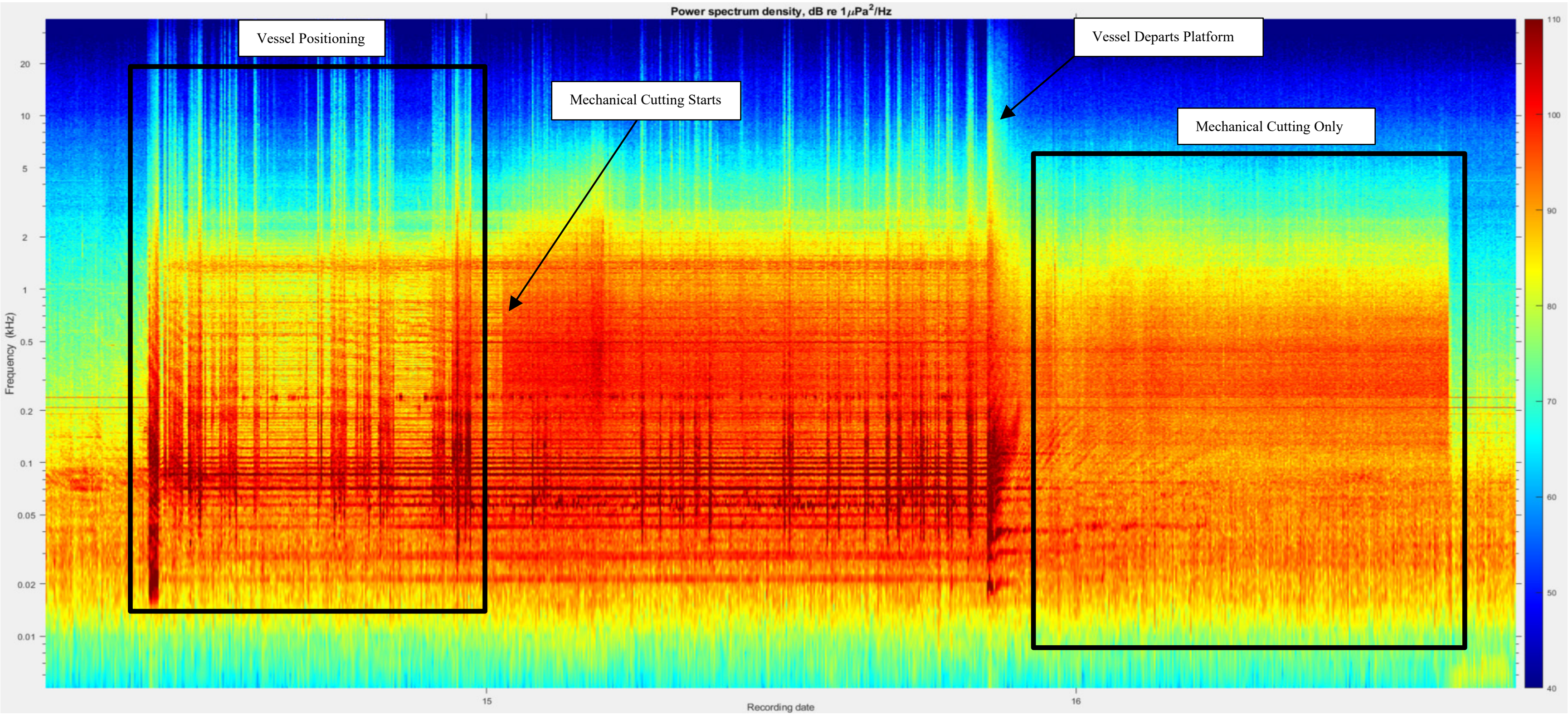


Figure 26. PSD Spectrogram Plot of B-16 Mechanical Cut from 14:19 to 16:37 (SoundTrap 5366)

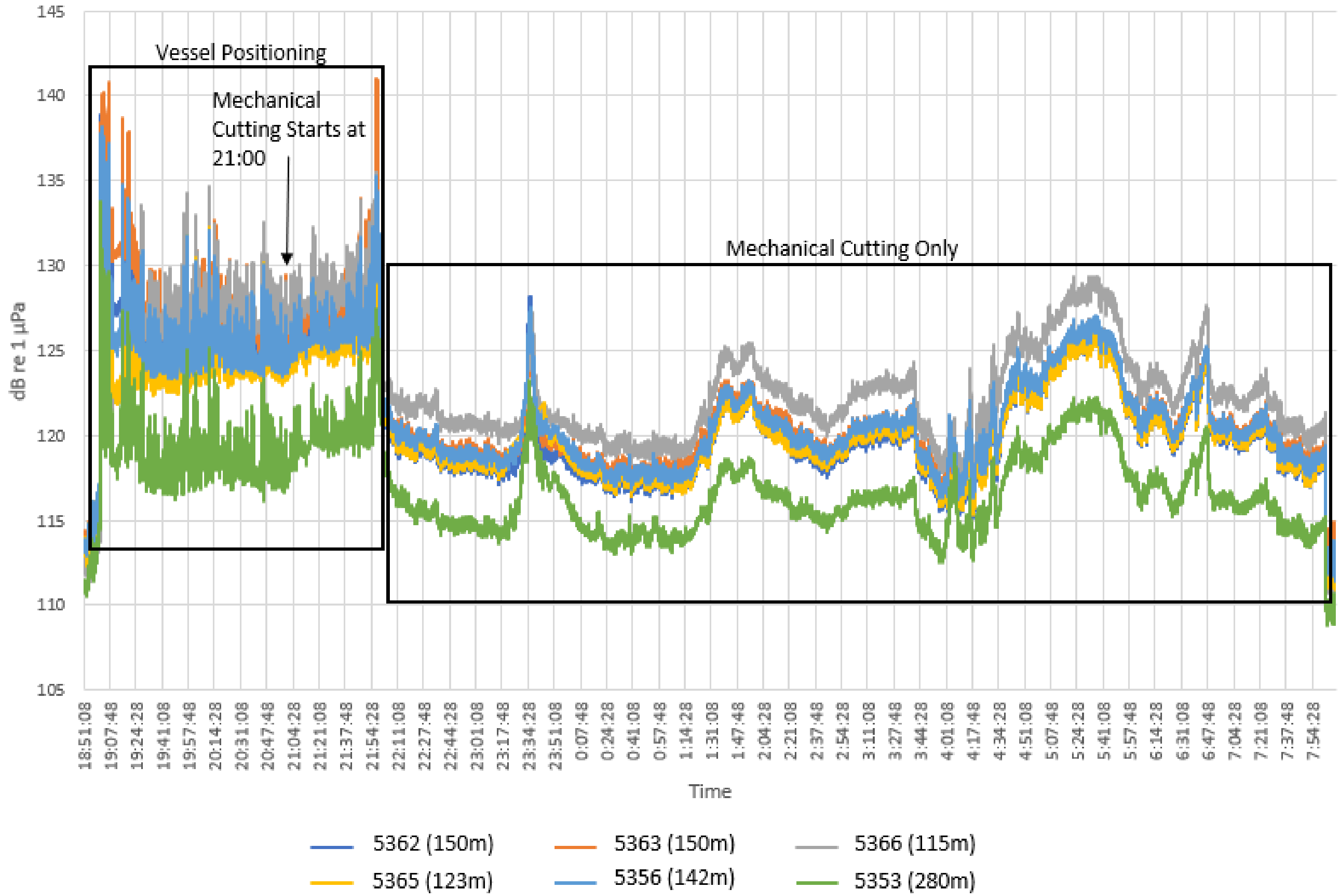


Figure 27. Time History Plot of B-16 Mechanical Cut from April 4, 2021, 19:00 to April 5, 2021, 8:03 (20-second sample interval)

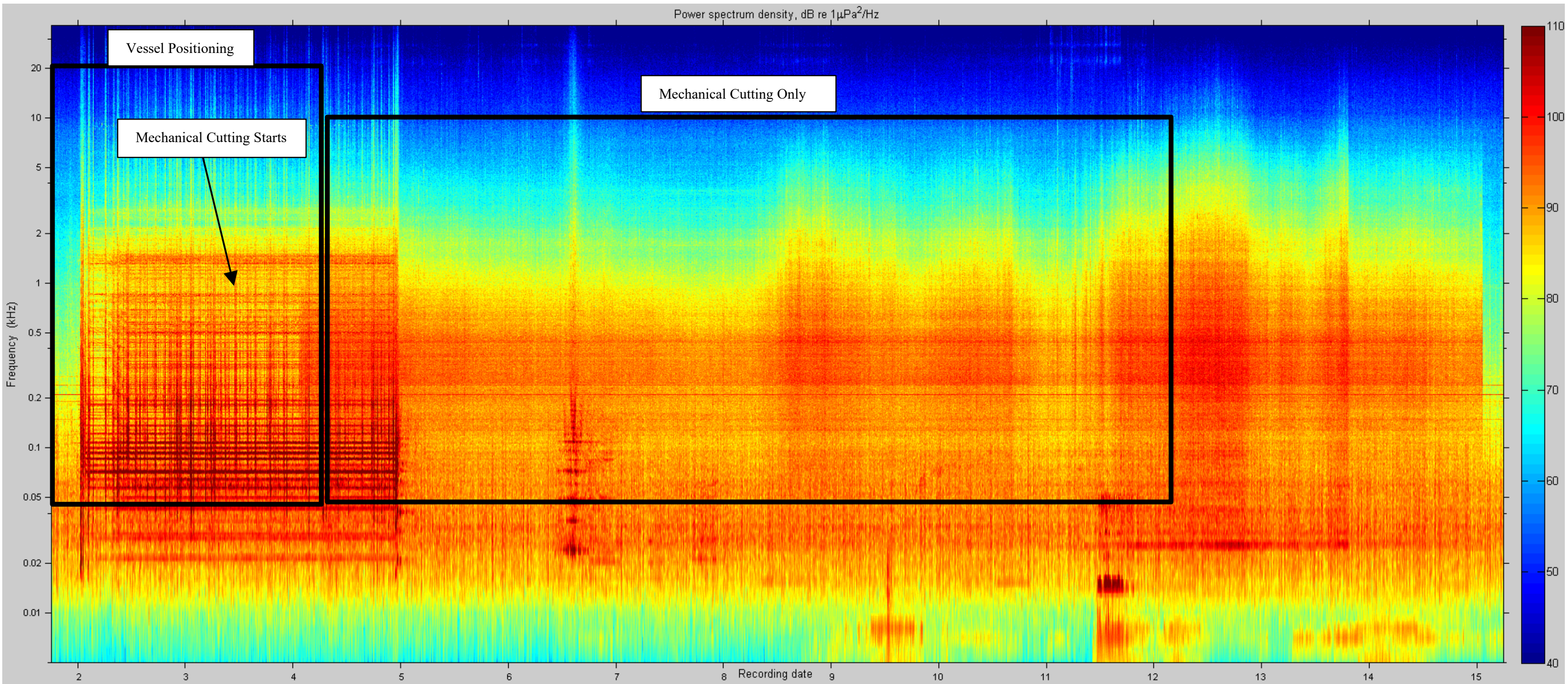


Figure 28. PSD Spectrogram Plot of B-16 Mechanical Cut from April 4, 2021, 19:00 to April 5, 2021, 8:03

SoundTrap 5363 was located within the mid-water column and shows the influence of the vessel operations during this cutting event. Figure 29 identifies the vessel operations and cutting operations in 1/3 octave bands. As shown in Figure 29, the vessel operation is the dominant sound majority of the spectrum. However, the cutting operations do show influence from 250 Hz to 800 Hz.

SoundTrap 5366, which is the closest to the cutting operations, shows more influence from the cutting operations. Figure 30 shows the 1/3 octave band SPL for the vessel and cutting operations sources as well as the combined sources.

As shown in Figure 30, the vessel operations 1/3 octave band is shown to dominate between 31.5 and 5,000 Hz. The cutting operations do influence sound between 250 and 800 Hz above the vessel sound. The combined sound from the vessel and cutting operations ranged from 125 dB SPL closest to the conductor (115 m [377 ft]) to 118 dB SPL at 280 m (918 ft) from the conductor. The SEL levels for the duration when both operations occurred range from 172 dB near the conductor to 165 dB at 280 m (918 ft) from the platform. The noise levels from only the mechanical cutting operations ranged from 123 dB SPL near the conductor to 117 dB SPL at 280 m (918 ft) from the platform. The SEL levels for the duration when only the mechanical cutting occurred range from 169 dB near the conductor to 163 dB at 280 m (918 ft) from the platform. Compared with the vessel operations, these levels show that the vessel operations had a 1 to 4 dB influence on the SPL levels and a 3 to 5 dB influence on the SEL levels.

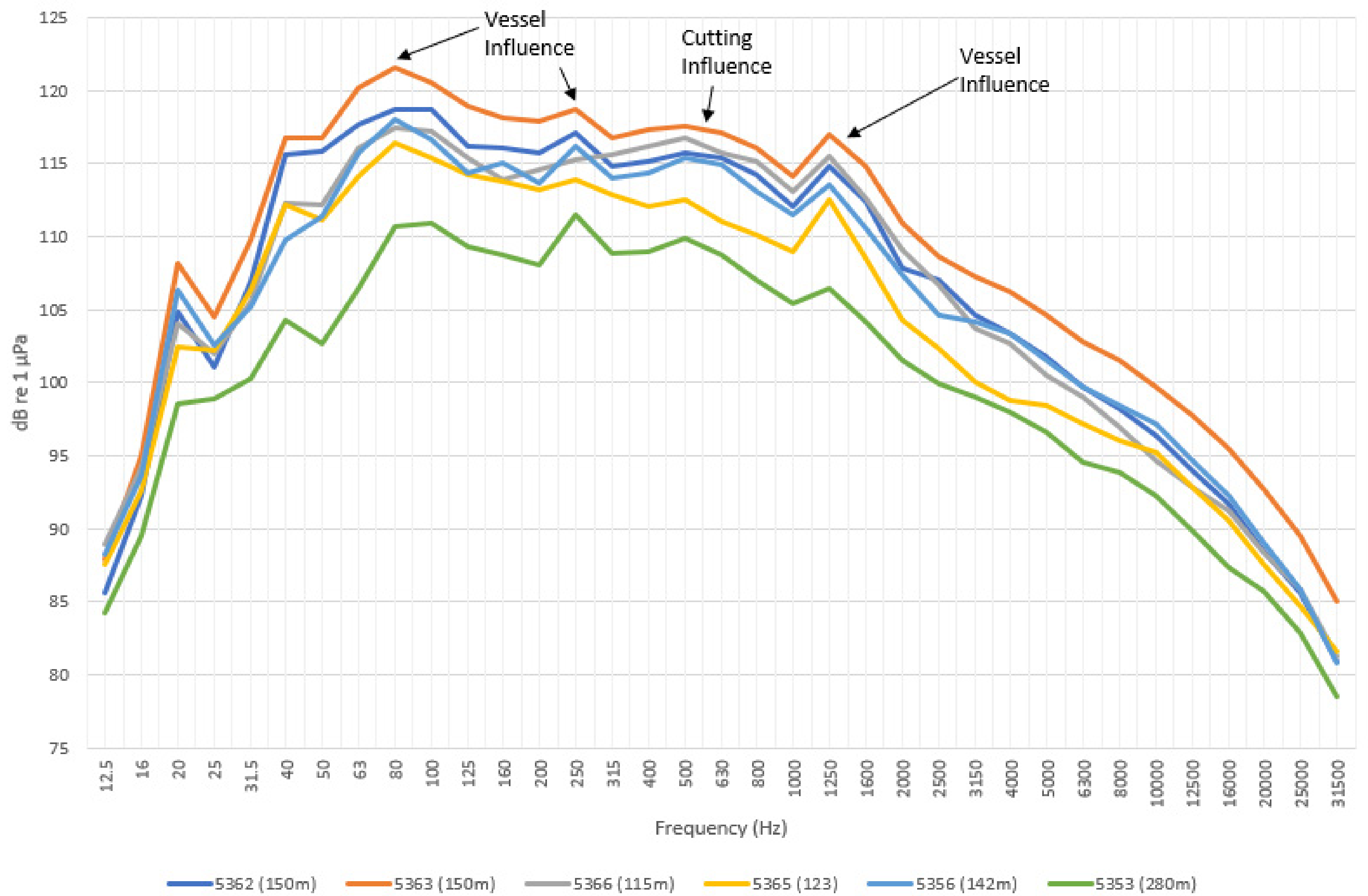


Figure 29. SPL RMS 1/3 Octave Band Plot of B-16 Mechanical Cut from April 4, 2021, 14:19 to 16:37

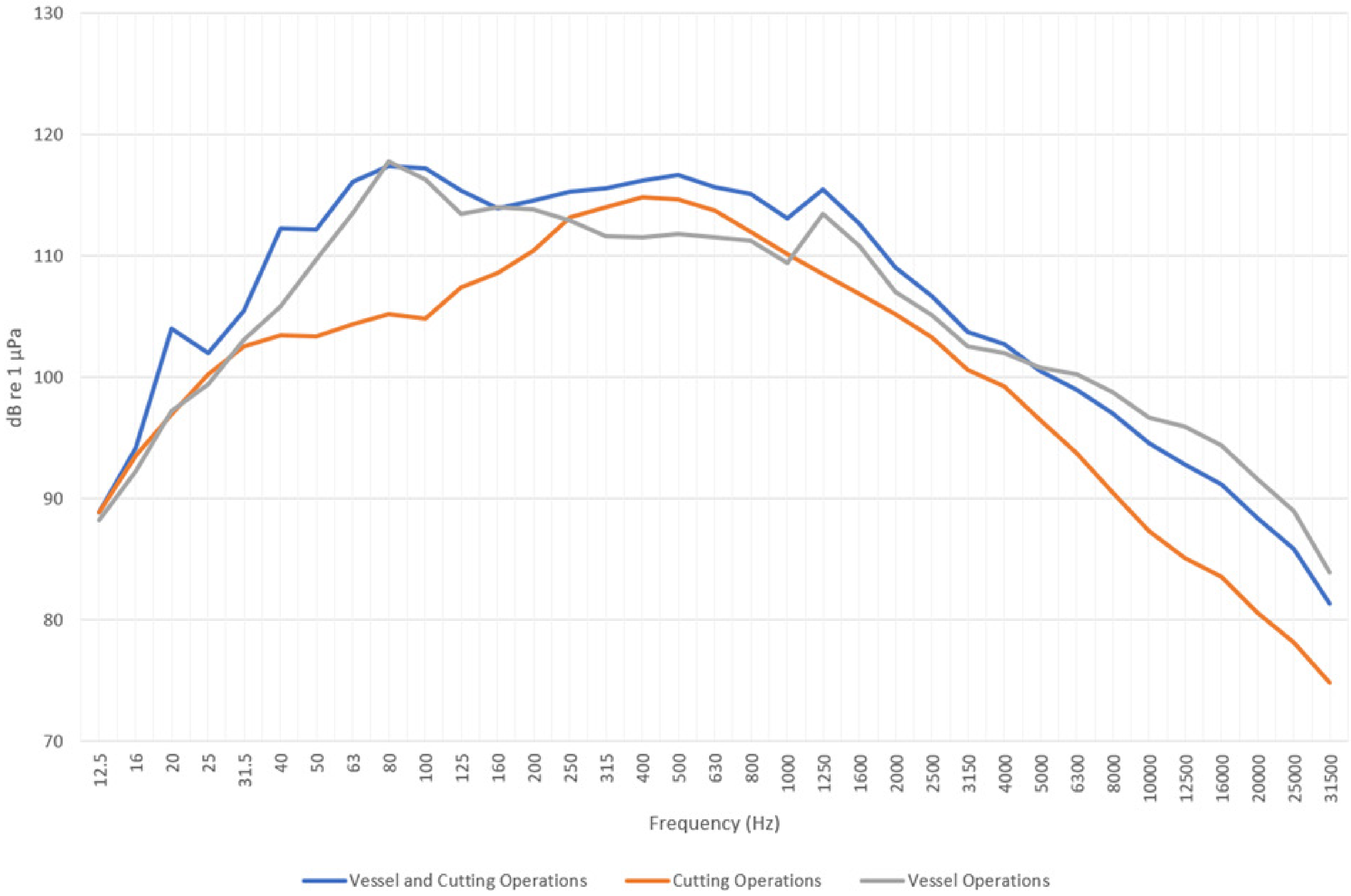


Figure 30. SPL RMS 1/3 Octave Band Plot of B-16 Mechanical Cut from 14:19 to 16:37 Comparing Vessel Noise to Mechanical Cutting Noise (SoundTrap 5366)

4.3.3 Acoustic Analysis of Secondary Operational Events

In addition to the mechanical cutting events identified in the logbook provided by Freeport, secondary operational events that generated noise levels above a certain threshold were also identified during the field program. In conversation with Freeport, these secondary operational events corresponded to activities before and after actual mechanical cutting. Activities included multiple trips in and out of the wellbores and conductors with the drill pipe and mechanical cutters to perform the mechanical cuts below the mudline. The trips out of the wellbore and conductors were to change out the knives due to wear or swap knives to a larger size knife. The trips in the wellbore or conductor were to get the mechanical cutter on depth to start or continue the mechanical cut. The mechanical cutter and pipe came in contact with the low side of the casing walls, creating residual noise in the water column. Noise associated with these secondary operational events is generally expected to be lower than that produced during actual cutting due to the lack of pumping action. Cuts reviewed above included those associated with wellbores and conductors B-16, B-3, S-29, and B-14. Secondary operational events occurred as part of the B-16 wellbore cuts, and the noise levels associated with those secondary operational events are described further below.

Review of measured sound levels associated with secondary operational events showed that levels range from 119 to 129 dB SPL at an approximate distance of 106 m (349 ft) from the platform (SoundTrap 5366) to 110 to 111 dB SPL at an approximate distance of 250 m (820 ft) from the platform (SoundTrap 5353). An example time history plot and 1/3 octave band plots for the secondary event that occurred at B-16 are shown in Figures 31 and 32. As expected, measured sound pressure levels were lower than during cutting events with some concentration in sound levels in the higher frequency range (5 kHz) likely corresponding to sound produced by a combination of on-platform equipment and vessel activity.

As part of the acoustic analysis, it was important to recognize that noise may be produced beyond the actual conductor cutting events; however, variability in the trips in and out of the wellbores and the resulting noise, make secondary events challenging to characterize in any consistent manner. Additional information related to secondary events is given in Appendix B.

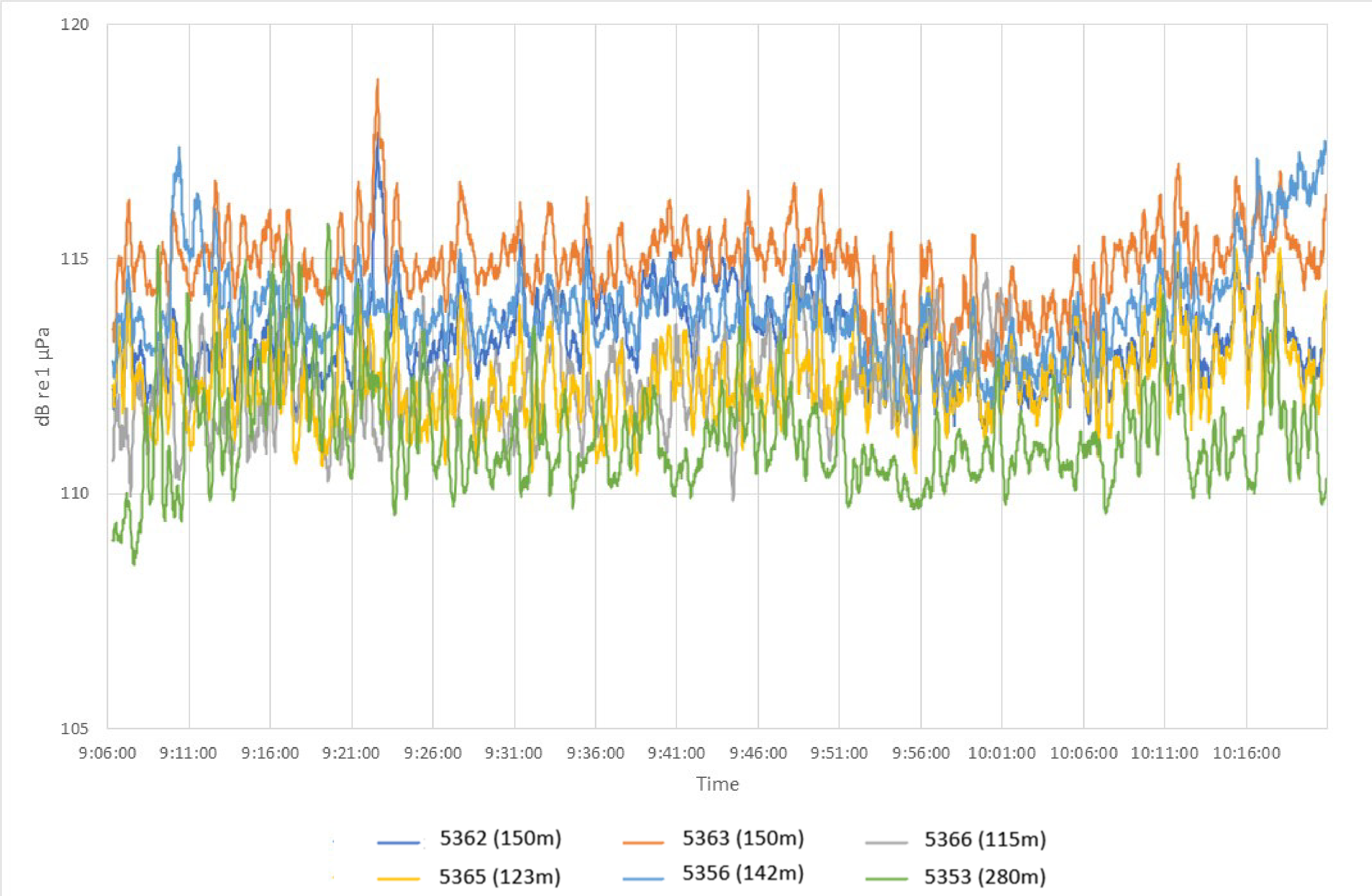


Figure 31. Time History Plot of B-16 Secondary Operational Event from April 4, 2021, 9:06 to 10:21 (20-second sample interval)

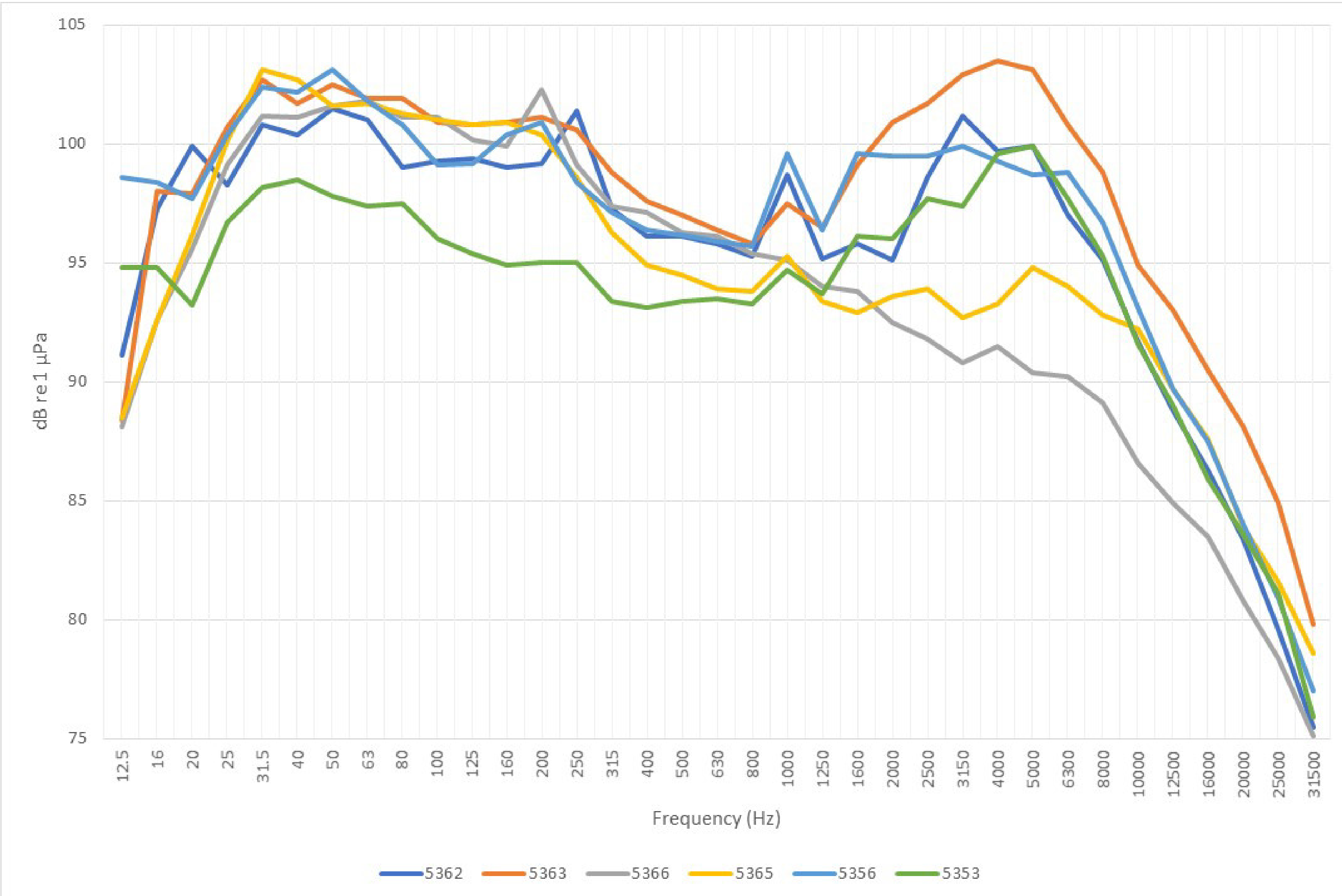


Figure 32. SPL RMS 1/3 Octave Band Plot of B-16 Secondary Operational Event from April 4, 2021 9:06 to 10:21

4.4 Marine Mammal Hearing Weightings

The noise data for all mechanical cuts were further evaluated for marine mammals by applying the NOAA hearing weightings (Figure 2). The marine mammal hearing weightings were applied to both the SPL and SEL metrics for the total duration of the cuts (see Table B-2 in Appendix B). The noise levels generated by the mechanical cutting activities are shown to be well below the marine mammal PTS onset acoustic thresholds and generally below TTS onset acoustic thresholds as presented in Table 1. There was only one instance observed in Table B-2 where an exceedance of the TTS threshold for HF cetaceans occurred when completing the first cut of B-13 wellbore. Given these findings, the 200 m (656 ft) monitoring zone was of an adequate size for monitoring marine mammals during cutting. The following list summarizes the potential for PTS or TTS with respect to marine mammal hearing groups:

- LF – no PTS or TTS exceedance.
- MF – no PTS or TTS exceedance.
- HF – no PTS exceedance. TTS exceeded at B-13. There were no HF marine mammals expected or observed in the Study area; however, if cutting occurred in other areas where HF animals occur, there is the potential for TTS.
- Phocid pinnipeds – no PTS or TTS exceedance.

4.5 Azimuthal Variability

The variability of acoustic radiation along an azimuth is the relative measure of acoustic energy propagating along a vertical plane in a single direction. Monitoring stations were placed on all four sides of the platform where the overall sound reduction in a single direction can be calculated. The reduction in each direction can then be compared to help determine the influence of obstacles (other conductors) in the path.

Calculations to determine the azimuthal variability exhibited during conduct cutting were completed for four conductors on both the east and west sides of the platform. The measured SPLs at each hydrophone were normalized to a distance of 100 m (328 ft). The ratio of the sound level distribution represented by each measurement could then be evaluated, essentially resulting in the azimuthal variability for each measured event. The sound level reduction was calculated based on the highest sound level and plotted for the conductors on the east and west sides of the platform. These plots are shown in Figure 33, along with the sound level reduction for each azimuth associated with the conductor-cutting activities.

The results of the azimuthal variability analysis show that conductor-cutting noise emissions are affected by other conductors located between the cutting operation and monitoring location. This reduction is shown to be as high as 4 dB when the cutting event occurs on the opposite side from the monitor location. The results of this analysis show there is an influence on the overall reduction as the cutting events get closer to the east side of the platform. After consulting with Freeport, it is understood that the diesel engine and pumps associated with the mechanical cutting were located on the east side of the platform near the vicinity of the conductor pipes. This likely influenced the azimuthal variability due to the influence of sound sources on the east side of the platform.

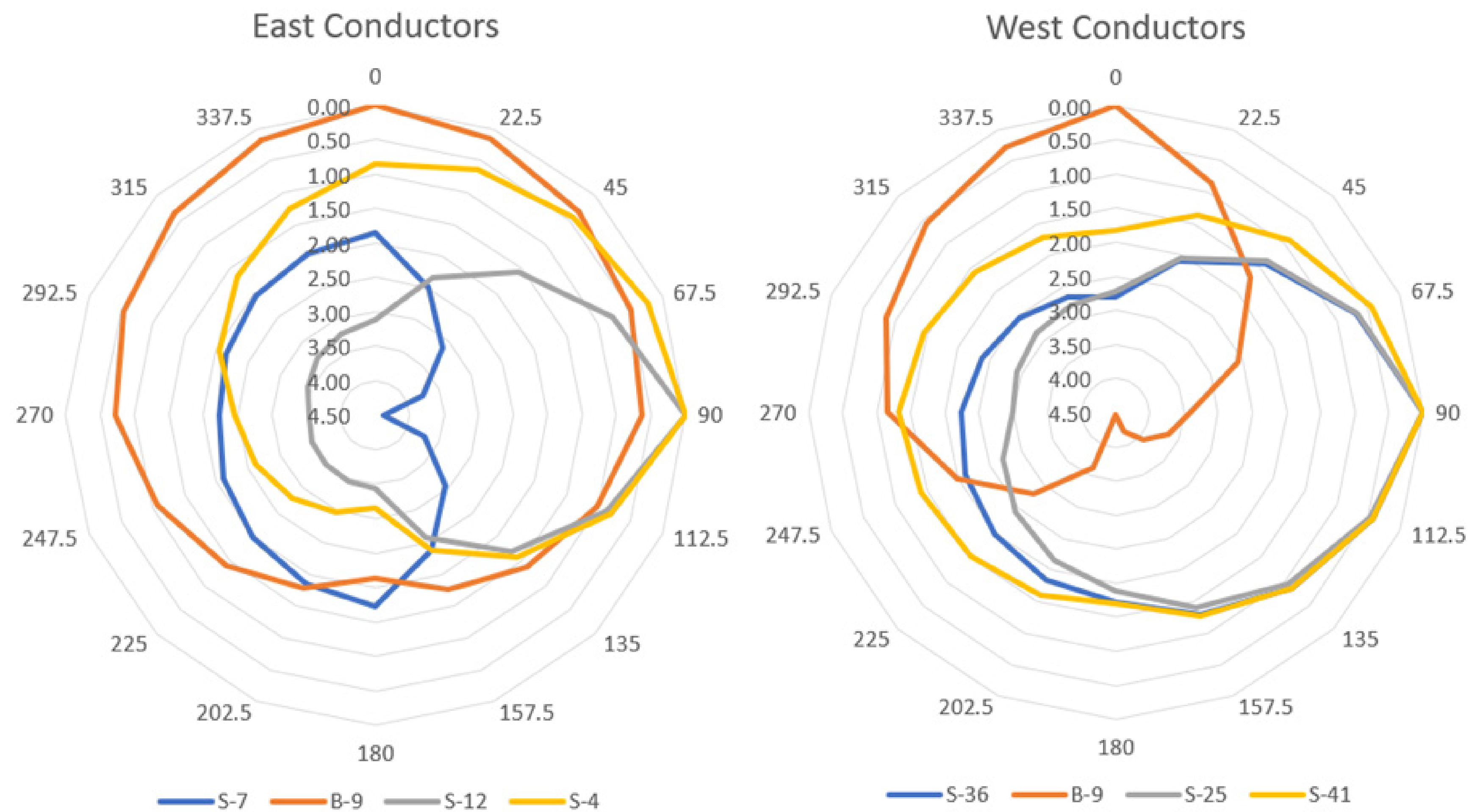


Figure 33. Conductor-Cutting Azimuthal Variability Analysis Results

4.6 Sound Propagation Analysis

Underwater sound propagation modeling was conducted to evaluate the sound propagation of a wellbore conductor and an empty conductor. Tetra Tech used dBSea for the underwater sound propagation modeling. dBSea is a software program developed by Marshall Day Acoustics for the prediction of underwater sound. The model is built by importing bathymetry data and placing noise sources in the environment. Each source can consist of equipment chosen from either the standard or user defined databases. The user has control over the seabed and water properties including surface salinity profile (SSP), temperature, salinity, and current. Noise levels are calculated throughout the entire bathymetry area. Levels are calculated in the third octave band range from 12 Hz to 20,000 Hz. For the Study, two different solvers are used for the low- and high-frequency ranges:

- dBSeaPE (Parabolic Equation Method): The dBSeaPE solver makes use of the parabolic equation method, a versatile and robust method of marching the sound field out in range from the sound source. This method is one of the most widely used in the underwater acoustics community and offers excellent performance in terms of speed and accuracy in a range of challenging scenarios.
- dBSeaRay (Ray Tracing Method): The dBSeaRay solver forms a solution by tracing rays from the source to the receiver. Many rays leave the source covering a range of angles, and the sound level at each point in the receiving field is calculated by coherently summing the components from each ray. This is currently the only computationally efficient method at high frequencies.

The underwater acoustic modeling analysis used a split solver, with dBSeaPE evaluating the 12.5 to 800 Hz range and dBSeaRay addressing the 1,000 to 20,000 Hz range. The specific parameters used in the modeling analysis are described below.

4.6.1 Bathymetry Data

Bathymetry data were obtained from the National Geophysical Data Center and a U.S. Coastal Relief Model (NOAA Satellite and Information Service 2020), and the horizontal resolution of this dataset is 3 arc seconds (90 m). The bathymetry data extended 20 mi from the Hermosa Platform. The conductor cutting sound sources were placed near the middle of the bathymetry area.

4.6.2 Sediment Characteristics

Seafloor properties were obtained through online research. The Development and Production Plan for Platform Hidalgo and its associated pipelines was completed by Chevron USA Inc. in 1984 and that report provided the needed information pertaining to the Study area sediment characteristics. The geoacoustic properties given in Table 7 were directly input into dBSea for each defined sediment layer. The properties detailed in Table 7 include the compressional sound speed (C_p) given in meters per second, which refers to the speed of sound in the sediment along the direction of acoustic propagation. In addition, the compressional attenuation (αs) is presented and refers to how much sound (dB) is lost per wavelength (λ) of the signal. Finally, density is the physical density (ρ) of the sediment in kilogram per cubic meter (kg/m^3).

Table 7. Geoacoustic Properties of Sub-bottom Sediments as a Function of Depth

Depth (m)	Sediment Type	Geoacoustic Properties
0 to 6	Soft Clayey Silt	Cp = 1575 m/s αs (dB/λ) = 1.0 dB/ λ ρ = 1700 kg/m^3
6 to 75	Sandy Silt	Cp = 1612 m/s αs (dB/λ) = 0.9 dB/ λ ρ = 1800 kg/m^3
75 to 115	Clayey Silt	Cp = 1538 m/s αs (dB/λ) = 0.6 dB/ λ ρ = 1600 kg/m^3

4.6.3 Speed of Sound Profile

Sound speed profile information used in the modeling analysis was obtained directly from the thermistor data collected during the field program. The sound speed sound profile was directly inputted into the dBSea model, and the input is shown in Figure 34.

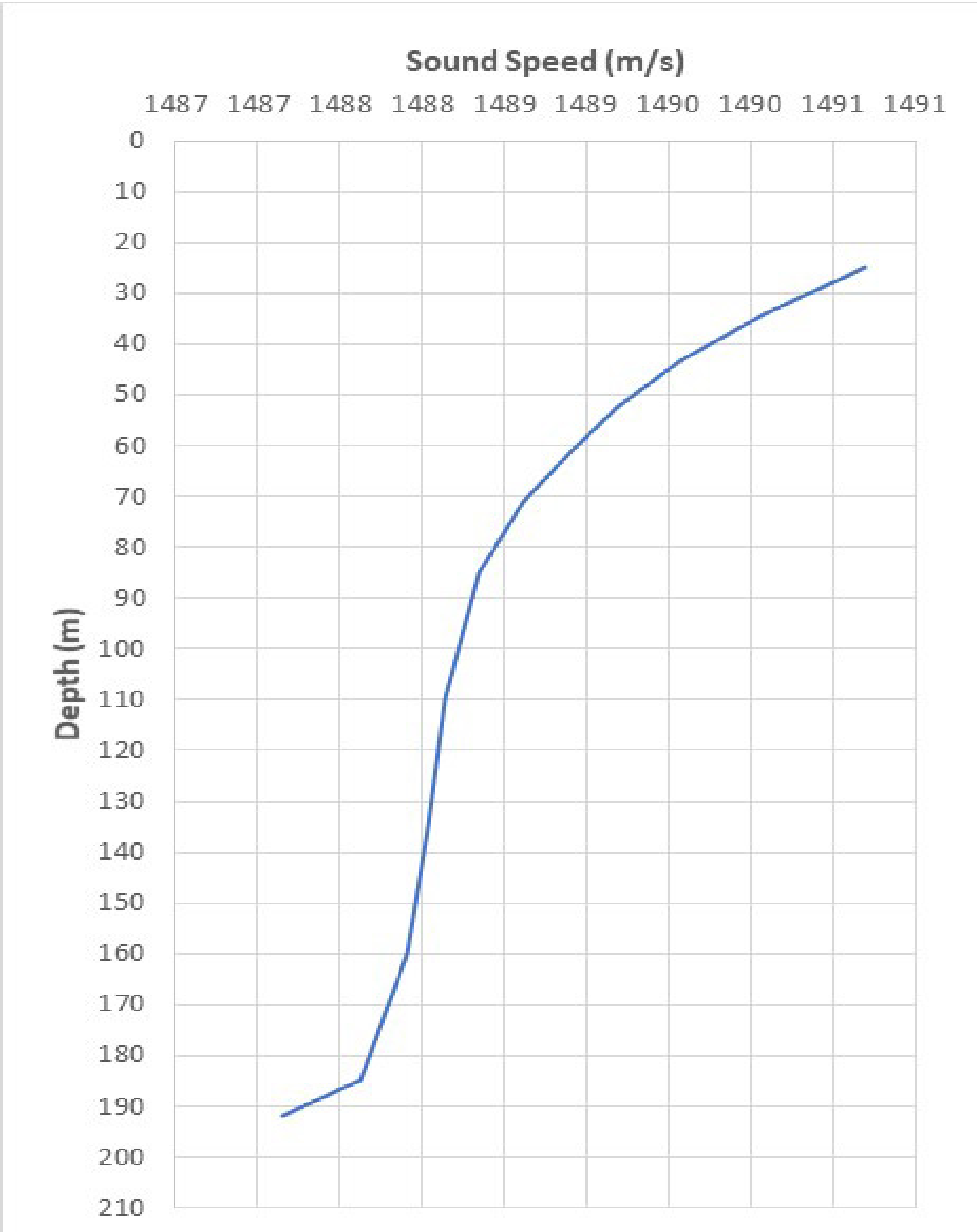


Figure 34. Study Area Sound Speed Profile

4.6.4 Conductor Cutting Sound Source Characterization

Sound source levels were developed for a wellbore conductor and empty conductor using measurement data. The two events evaluated using the sound propagation model were the wellbore conductor B-14 first cut occurring on April 14, 2021, from 17:06 to 19:05 and the empty conductor S-29 cut occurring on April 7, 2021, from 18:35 to 19:17. These cutting events were chosen because they are representative of the cutting operations for both the wellbore and empty conductors. They are also events that were not influenced by the supporting vessel.

The SPL frequency spectrum for the full duration of each cut from SoundTrap 5366 was used as a source level, which provided the most conservative values and were back-calculated to obtain the conductor cutting sound source level. The duration of the event was also applied to calculate the SEL level for each event. The mechanical cutting was modeled as a vertical line source and the speed of sound of steel was accounted for within the line source to account for the radiated sound. The vertical array was divided into eight separate and equal sections extending from the top to the bottom of the water column. The source level and spectrum inputted into the model are summarized in Table 8 and Figure 35.

Table 8. Conductor Cutting Source Level

Conductor	Cutting Event Duration (sec)	Sound Source Level
B-14	2,573	163 Lp
S-29	7,090	166 Lp

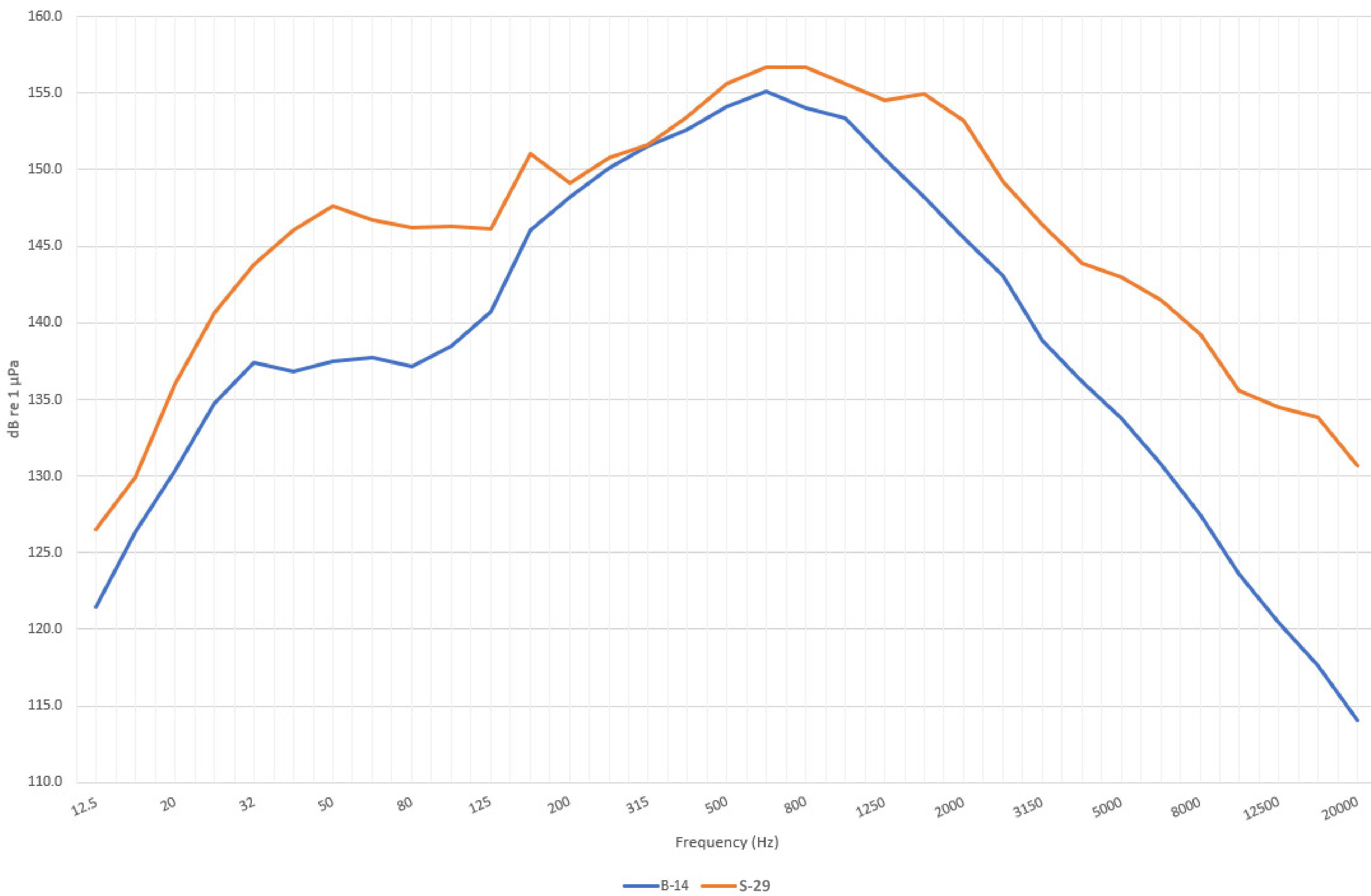


Figure 35. Conductor Cutting Source Level Spectrum

The results of the model were compared to the measurement results. A difference of ±4 dB is considered reasonable for calibration of the sound propagation model based on the azimuthal variability. Table 9 shows the results of the model calibration at the monitoring locations for both the SPL and SEL metrics.

Table 9. Sound Propagation Model Calibration Results

Conductor	Monitor Name	L_p (dB)			L_E (dB)		
		Measured Level	Modeled Level	Difference	Measured Level	Modeled Level	Difference
B-14 4/14/2021 17:06-19:05	5362	125.3	125.8	0.5	163.8	164.8	1.0
	5363	125.1	128.0	2.9	163.7	167.0	3.3
	5366	129.7	126.7	3.0	168.2	165.7	2.5
	5365	125.1	126.0	0.9	163.6	165.0	1.4
	5356	124.5	122.3	2.2	163.1	161.3	1.8
	5353	119.6	117.3	2.3	158.2	156.3	1.9
S-29 4/7/2021 18:35-19:17	5362	127.5	128.7	1.2	161.6	162.7	1.1
	5363	127.5	127.7	0.2	161.6	161.7	0.1
	5366	132.4	133.8	1.4	166.5	164.5	2.0
	5365	130.3	130.9	0.6	164.4	164.9	0.5
	5356	127.1	129.7	2.6	161.2	163.7	2.5
	5353	123.7	126.0	2.3	157.8	160.3	2.2

L_p = (dB re 1 μPa); L_E = (dB re 1 μPa^2·s)

For the B-14 cut, all the locations met the calibration criteria of ±4 dB for both the SPL and SEL results. For the S-39 cut, the model provided similar results with all locations meeting the criteria for both the SPL and SEL results.

With the model calibration confirmed, sound propagation calculations were completed for a radius of 16 km (10 mi) from the source. These results were then used to determine the distances to the marine mammal permanent threshold shift onset as well as the marine mammal and fish behavioral response thresholds for each event (Table 10 and Table 11).

Table 10. Marine Mammal Permanent Threshold Shift Onset Maximum Threshold Distances (Meters) for Modeled Mechanical Cuts

Conductor	Hearing Group			
	Low-Frequency Cetaceans	Mid-Frequency Cetaceans	High-Frequency Cetaceans	Phocid Pinnipeds
	199 L_E	198 L_E	193 L_E	201 L_E
B-14 4/14/2021 17:06-19:05	N/A	N/A	N/A	N/A
S-29 4/7/2021 18:35-19:17	N/A	N/A	N/A	N/A

L_E = (dB re 1 μPa^2·s)

Table 11. Marine Mammal and Fish Behavioral Response Maximum Threshold Distances (Meters) for Modeled Mechanical Cuts

Conductor	Hearing Group	
	Fish	Marine Mammals
	150 L_p	120 L_p
B-14 4/14/2021 17:06-19:05	6	205
S-29 4/7/2021 18:35-19:17	9	663

L_p = (dB re 1 μPa)

Table 10 shows that the mechanical cutting activities do not generate noise levels high enough to exceed the thresholds for marine mammal PTS onset. This is supported by the data in Table B-2 that show the measured data for each cut with the applied marine mammal hearing weightings.

Table 11 shows that the distance to threshold for fish behavioral response is less than 10 m (33 ft) from the source. The marine mammals' behavioral response distance ranges from 205 to 663 m (673 to 2,175 ft). Figures 36 and 37 show the SPL RMS noise propagation contours for the modeled mechanical cutting events.

The mechanical cutting events were modeled as a line source with noise being generated for the full depth of the water column. Figure 38 shows the cross-section view for conductor S-29 modeled mechanical cuts.

4.7 Marine Mammal Occurrence and Analyses

Marine mammal visual observation was conducted from Platform Hermosa by Freeport from March 19 through April 21, 2021. Per Bureau of Safety and Environmental Enforcement requirements, one trained observer was required to monitor a 200-m (656-ft) zone 30 minutes prior to cutting activities to ensure no protected species were in the zone. If species were detected, cutting activities were delayed until the protected species were seen more than 200 m (656 ft) away from the cutting site. Observer monitoring forms were provided to Tetra Tech by Freeport and show that only one sighting occurred from Platform Hermosa; this sighting occurred on April 15 of two whales, unidentified to species level. Activities were delayed until the whales left the area. A number of cutting events occurred at night, in the dark, and some in bad weather.

Marine mammal occurrence was detected acoustically through the analysis of data from one passive acoustic recorder. Marine mammal detections were successfully obtained and several follow-on analyses related to these calls were conducted. Acoustic deliverables from the marine mammal analyses are accessible via the Tetra Tech hard drive deliverable, with the exception of the training video for Appendix D which accompanies this Final Report.

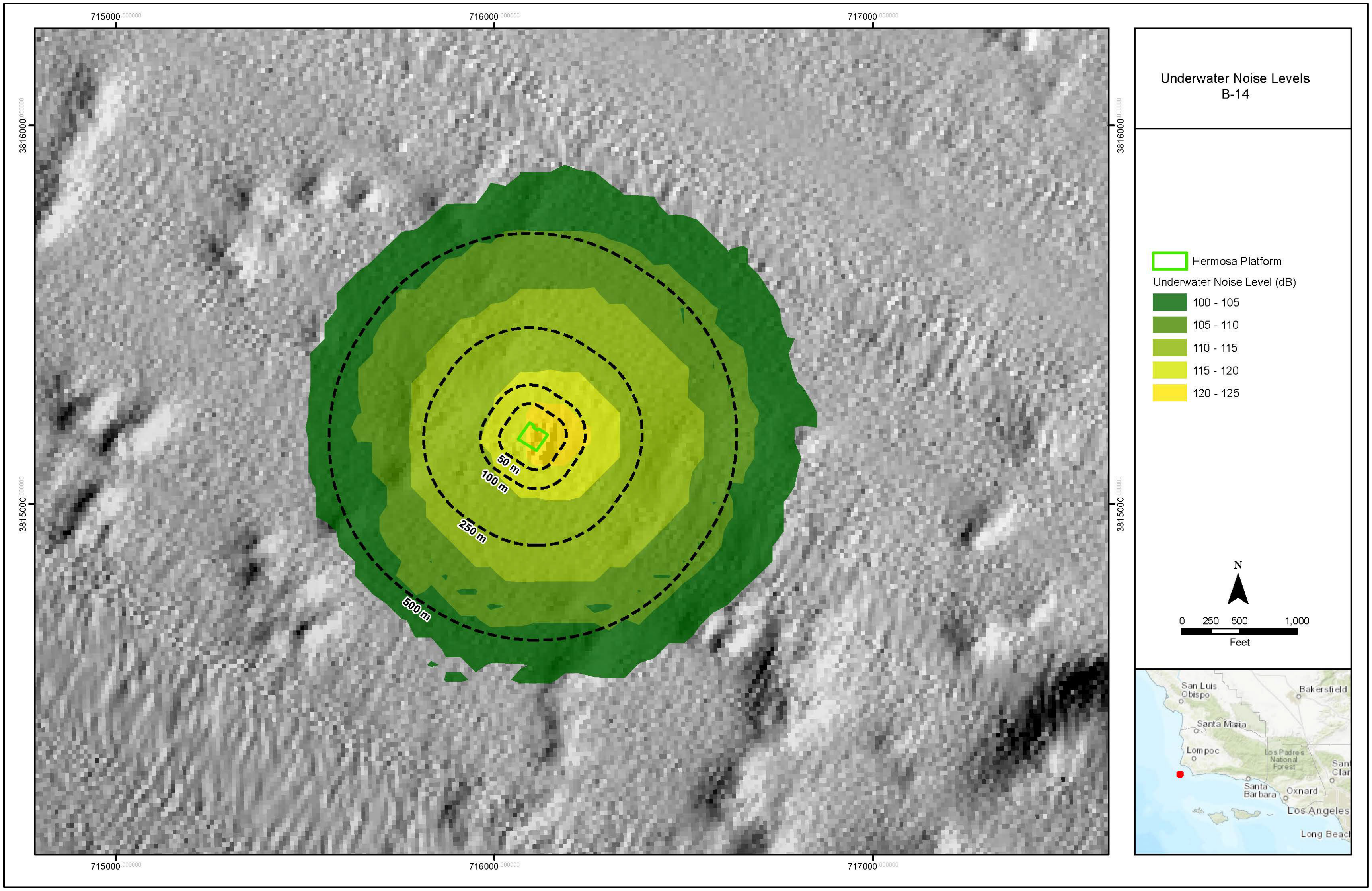


Figure 36. SPL RMS Noise Model Propagation Results for the B-14 Wellbore

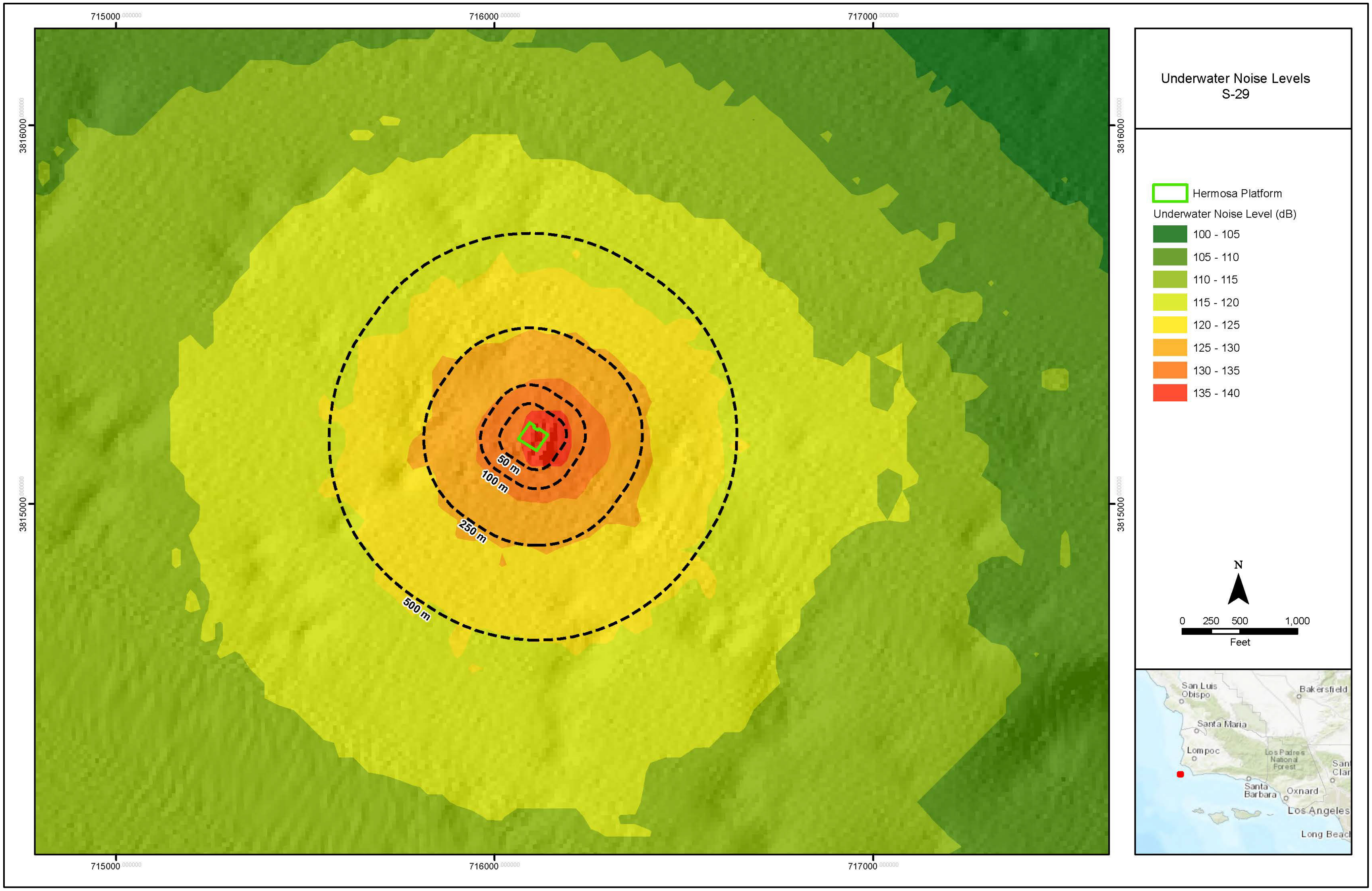


Figure 37. SPL RMS Noise Model Propagation Results for Empty Conductor S-29

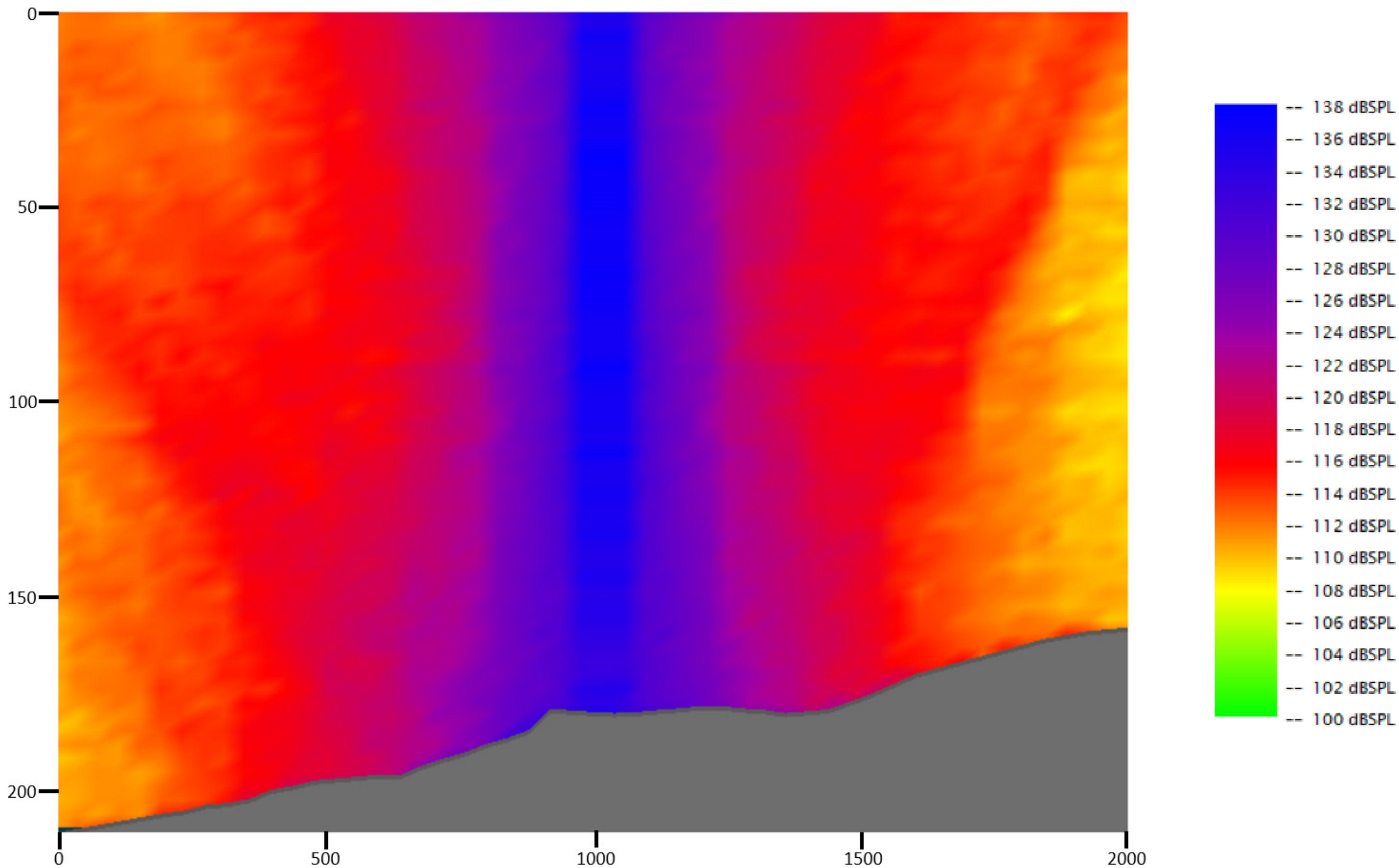


Figure 38. SPL RMS Noise Model Propagation Results Cross-Section View

4.7.1 Marine Mammal Species Occurrences and Detection Events

Marine mammals were acoustically detected throughout the field program. The persistent sources of noise (e.g., cutting periods, ship traffic to and from the platform, etc.) periodically masked the marine mammal signals of interest, which reduced the ability to detect calls with a lower signal to noise ratio. However, PAMGuard's detectors perform well in noisy environments and detection of marine mammal calls of sufficient amplitude that overlap with the various sources of anthropogenic noise was still possible and only calls audible above the anthropogenic noise level were selected for events. A summary of the acoustic events by marine mammal species or species group is described in Table 12.

Table 12. Summary of Acoustic Events by Species along with Cumulative Event Duration Across All Events for Each Species or Species Group

Species/Species Groups	Number of Events	Cumulative Event Duration (Hour: Minute)
Delphinid Species	40	76:05
Humpback Whale	40	295:14
Sperm Whale	3	2:38
Unidentified Low Frequency Sounds	5	9:52
Unidentified Odontocete	1	1:05

The analyses showed that humpback whales occurred most frequently and were noted in over half of the total deployment duration, followed in frequency of occurrence by delphinid species. Sperm whales were not encountered often and were recorded only intermittently during three events; likely these were distant animals. A set of "Unidentified Low frequency Sounds" were coded that could not be identified as a specific species or species group. The anthropogenic noise in the LF ranges largely masked these signals. These calls were discernible despite the noisy shallow environment of the recorder mooring. Humpback whale calls only occurred in lower frequencies (between 200 Hz and 2 kHz) and were audibly discernible. Figure 39 provides an example of the typical humpback whale calls observed in the field program dataset. There were 40 separate events acoustically detected of humpback whale calls vocalizations and of vocalizations from delphinid species. There were three sperm whale detections, five unidentified LF calls, and one detection of an unidentified odontocete. Marine mammal acoustic events were distributed throughout the 3-week period often overlapping with cutting noise.

Delphinids encountered during the monitoring period produced echolocation clicks and burst pulsed calls. The burst pulse calls were easily detected above the upper range of the anthropogenic noise. An example of the commonly encountered burst pulsed calls is provided in Figure 40.

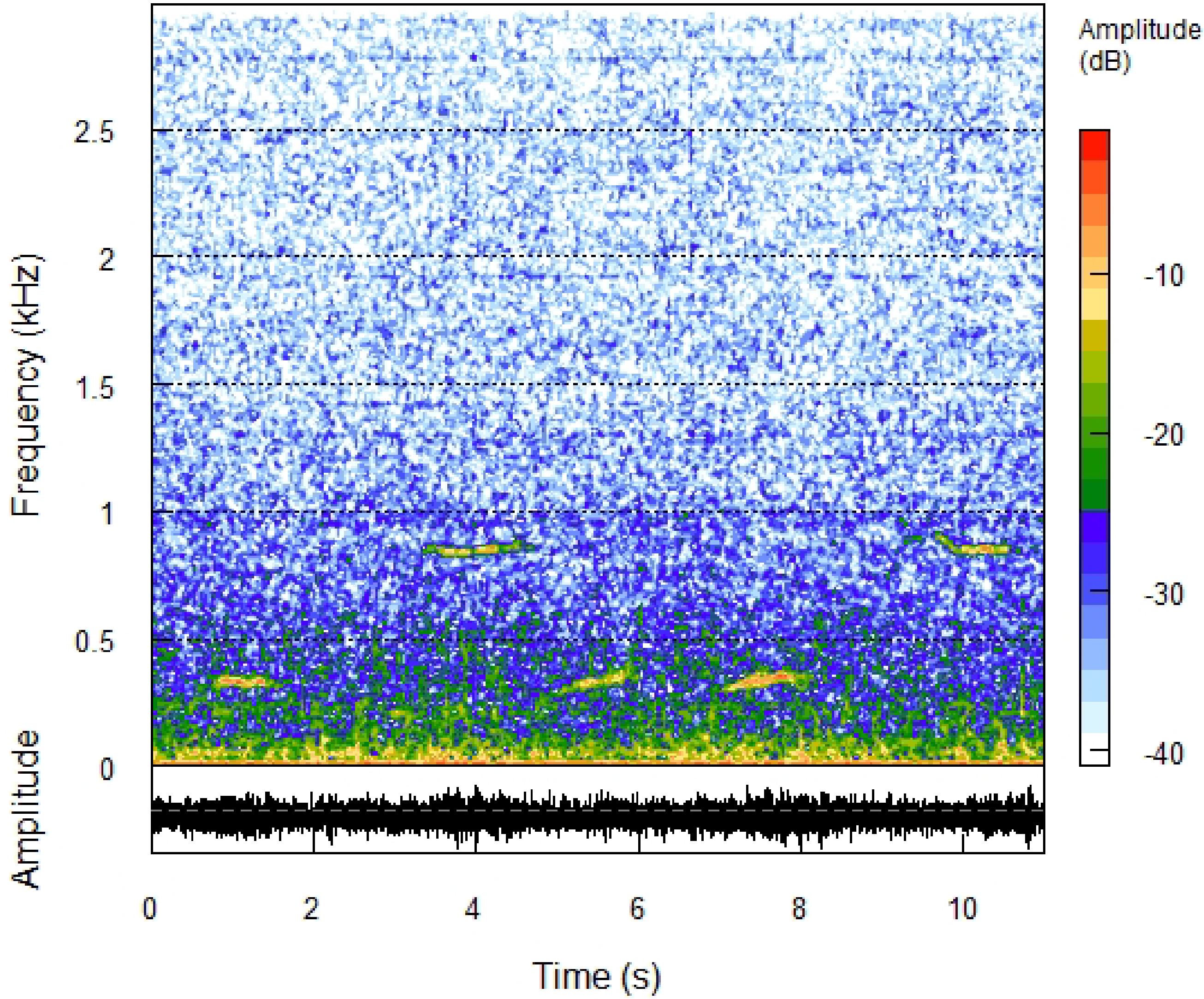


Figure 39. Waveform and Spectrogram of Tonal Calls from a Humpback Whale

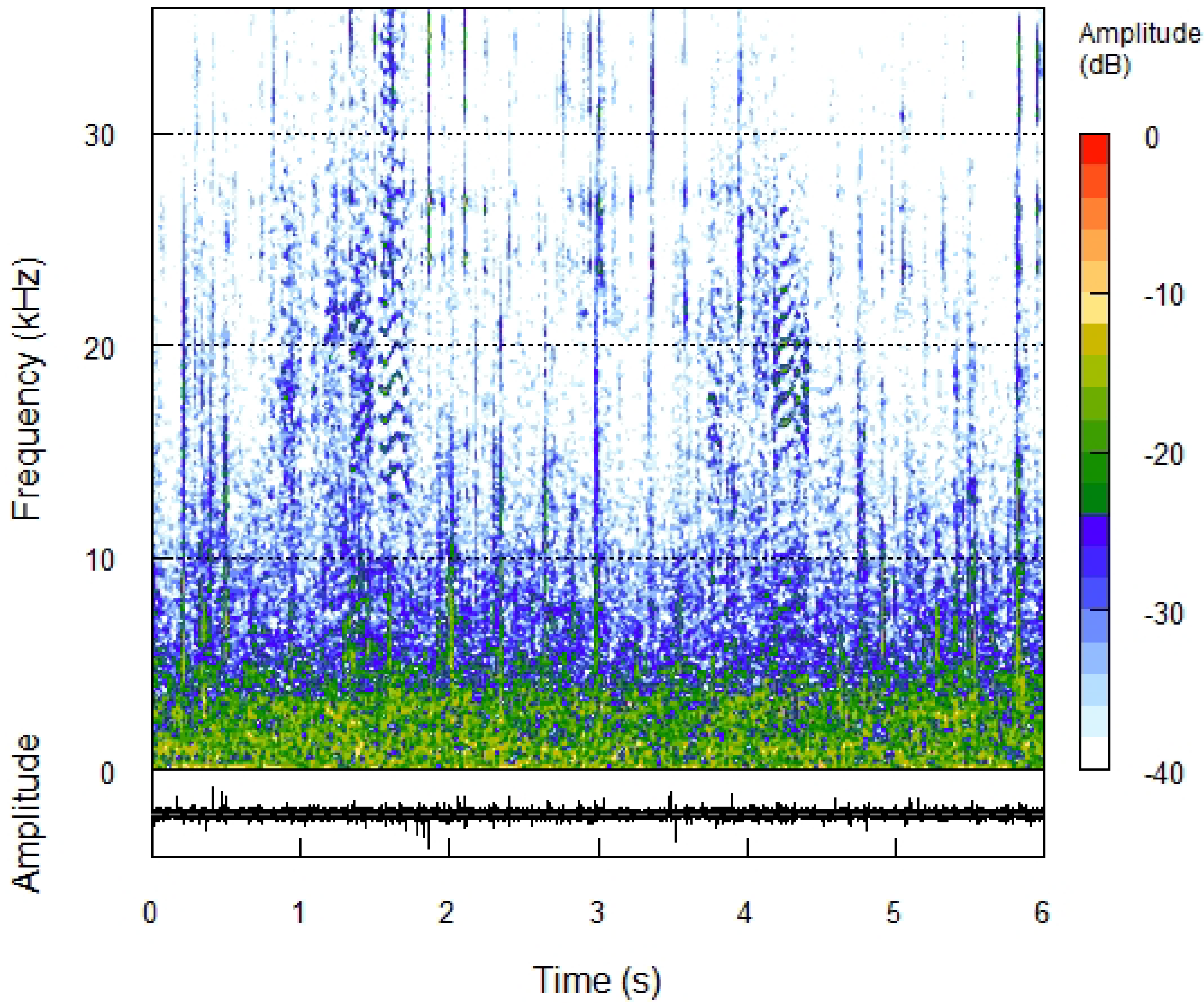


Figure 40. Waveform and Spectrogram of Tonal Calls from a Delphinid Species Event

4.7.2 Marine Mammal Calls Overlapping with Anthropogenic Noise

Tetra Tech noted anthropogenic noise sources overlapping with marine mammal calls. PAMGuard's detectors perform well in noisy environments, and detection of marine mammal calls of sufficient amplitude that overlap with the various sources of anthropogenic noise was possible. Calls audible above the anthropogenic noise level were obtained and selected for review. Table 13 provides a summary of the duration of anthropogenic noise events encountered during this analysis and compares them to species acoustic events. The number of noise events documented in Table 13 differ from the number noted in Section 4.2 because the table below was not confined solely to cutting events. Events for this analysis were defined to include other noise sources such as vessels, echosounders, pipe insertions, or other anthropogenic events.

Table 13. Summary of Anthropogenic Noise Source Detections by Number of Events and Duration

Type of Noise	Number of Events	Cumulative Event Duration (Hour: Minute)
Anthropogenic Noise (noise associated with cutting operations)	79	223:00
Echosounder	5	00:40
Ship passing	12	4:43

4.7.3 Marine Mammal Location

As the analysis was limited to a single acoustic station, the distance of the marine mammals relative to the platform could not be accurately determined. Conversely, general information can be provided about the detection distances of the most frequently detected species (i.e., humpback whales and delphinid species). Detection distances for humpback whale calls are significantly impacted by regional bathymetric characteristics and ambient sound levels due to their variable source levels and frequency ranges. Generally speaking, detection distances of 10 to 20 km (5.4 to 10.8 nautical miles [nmi]) is considered typical, with detection distances of up to 30 km (16.2 nmi) observed in conditions that favor extended sound propagation (Clark and Clapham 2004; Helble et al. 2013). Delphinids produce a variety of calls including whistles, echolocation clicks, and burst pulses. Previous studies of detection distances from towed hydrophone arrays in the Pacific Ocean on delphinids found mean detection distances for delphinids between 1 and 5.5 km (0.5 and 3 nmi; Rankin et al. 2008) though distances varied depending on species and vocalization type, i.e., whistles propagate farther than echolocation clicks.

Further complicating marine mammal call detection was the noise produced by the conductor cutting activities themselves. The cutting noise was found to be dominant in the lower frequency range (~100 Hz to 8 kHz) and the temporal distribution of marine mammal acoustic events was found to overlap with anthropogenic noise frequently, including with cutting noise. The contributions to anthropogenic noise from conductor cutting were easily identified through review of the LTSAs and spectrograms generated. Study-related sources of anthropogenic noise (i.e., cutting periods) dominated the 0 to ~12 kHz bandwidth of data, due to the proximity of the shallow recorder (>200 m) (>656 ft) to the platform.

4.7.4 Marine Mammal Call Frequency

The marine mammal call frequency was also evaluated in response to cutting noise. Originally it was expected that ambient sound data would be collected before and after the field program and used for the evaluation of call frequency; however, changes in the deployment schedule resulted in a revision to this approach. Since conductor-cutting periods have start and stop periods, review of marine mammal vocalizations occurred during periods immediately preceding, during, and immediately following cutting events.

PAMGuard is industry standard software used to obtain the received level amplitudes to evaluate if a species is within a mitigation zone. Received levels are influenced by animal movement, changes in call rate, and competing background noise; therefore, changes in amplitude from a fixed recorder over a short period of time cannot be confirmed as short-term changes in vocal behavior in this scenario. Nonetheless, changes in frequency parameters to compensate for increasing background noise have been documented using PAMGuard (Papale et al. 2015). In that study, frequency parameters of tonal calls included measurements of the minimum, maximum, beginning, and end frequencies. These values are independent of amplitude and can be easily observed if a high signal to noise ratio of calls exists.

First, conductor-cutting noise periods were identified that overlapped with the annotated marine mammal acoustic events. Each appropriate period was then reviewed to determine if the signal to noise ratio and the occurrence of calls within an acoustic event were sufficient for the analysis. Identified calls could then be measured manually to obtain better resolution in the frequency parameters than were determined in autodetection. These data were compared to values of third octave band SPLs to evaluate changes in the spectral characteristics. It was determined that the humpback whale dataset was best for this analysis due to its larger sample size; however, due to an insufficient number of calls and the low signal to noise ratio, the sample size was still not large enough to effectively conduct the call frequency analysis.

4.7.5 Acoustic Indices

A novel evaluation of acoustic indices was conducted. As mentioned in Section 3.4.1, acoustic indices were organized into three categories to compare to marine mammal calls and cutting periods. Data from delphinid and humpback whales had a sufficient sample size to evaluate indices and thus these calls were used. The ACI, BI, and NDSI calculations were successfully calculated and compared to several call parameters including call count, mean amplitude, mean minimum frequency, and mean maximum frequency of the detected calls from humpback whales and from delphinid species.

4.7.5.1 Indices and Marine Mammal Calls

All indices were non-parametric. Thus, a Kruskal Wallis Test[2] was used to look for differences between the values calculated for periods with delphinids, periods with humpback whales, and periods without vocalizing marine mammals. Results were as follows:

- Statistically significant differences were found for ACI ($H(2) = 82.29$, $p< 0.001$), BI ($H(2) = 32.41$, $p<0.001$), and NDSI ($H(2) = 96.06$, $p<0.001$).
- However, the effect size for this difference was considered trivial for ACI ($\eta^2 = 0.015$), BI ($\eta^2 = 0.006$), and NDSI ($\eta^2 = 0.018$).
- Post hoc comparisons using a Dunn's test[3] for ACI values showed:
    - Significant differences both between delphinids and no vocalizations ($p < 0.001$), and humpback whales and no vocalizations ($p < 0.001$); and

[2] The Kruskal-Wallis H test (sometimes also called the "one-way ANOVA on ranks") is a rank-based nonparametric test that can be used to determine if there are statistically significant differences between two or more groups of an independent variable on a continuous or ordinal dependent variable. It is considered the nonparametric alternative to the one-way ANOVA, and an extension of the Mann-Whitney U test to allow the comparison of more than two independent groups.

[3] Dunn's test is a non-parametric pairwise multiple comparisons procedure based on rank sums, often used as a post-hoc procedure following rejection of a Kruskal–Wallis test.

    - No significant difference between values with delphinids and humpback whales ($p = 0.475$).
- Post hoc comparisons for the BI values reflected the same differences as ACI.
- For the NDSI variable, the post hoc comparisons indicated:
    - A significant difference between values with delphinids versus humpbacks ($p < 0.001$).
    - A significant difference between values with humpback whales and no vocalizations ($p < 0.001$); and
    - No difference between periods with delphinids and no vocalizations ($p = 0.207$).

4.7.5.2 Indices and Conductor Cutting

The distribution of acoustic indices values measured during periods with and without cutting were analyzed using a Mann-Whitney U Test[4] to look for statistically significant differences in these values.

- A statistically significant difference was found in the ACI values for periods with cutting (Median [Mdn] = 10,059, $\sigma = 314$) and without cutting (Mdn = 10,132, $\sigma = 339$; U = 4.35e+6, $p < 0.001$), although the effect size indicated this was only a small difference ($r_B = 0.124$).
- Similarly, BI had a statistically significant difference in the values for periods with cutting (Mdn = 27.707, $\sigma = 2.063$) and without cutting (Mdn = 27.461, $\sigma = 2.144$; U = 3.55e+6, $p < 0.001$), with a small effect size (rB = -0.083).
- The analysis for NDSI indicated an even smaller difference in effect size ($r_B = 0.042$) between the values for periods with cutting (Mdn = -0.963, $\sigma = 0.021$) and without cutting (Mdn = -0.962, $\sigma = 0.022$; U = 4.03e+6, $p = 0.007$).

4.7.5.3 Indices Results Summary

The results of the acoustic indices analysis provided insight into the dynamics of sound in this environment but did not show a useful relationship to marine mammal vocalizations. The reason behind the lack of correlation between the indices and acoustic events is likely that the ambient and anthropogenic noise sources in the Study area were dominant relative to the biological noise present in the dataset.

The acoustic indices analysis did not result in a predictive correlation for biophony or anthrophony in this dataset. In testing of their use as indicators of periods of noise or marine mammal vocal activity, Tetra Tech found the measurements to be confounded by overwhelming noise from the platform activities. It is likely they would still be useful if recorders are located farther from the platform. This would allow differences in acoustic measurements to be more noticeable, i.e., not masked by conductor noise. This is a persistent source of error with the use of these indices (i.e., boat noise eradicates these indices).

4.7.6 Neural Network Results Summary

The neural network effort resulted in the successful creation of two deep neural networks that can be used for the detection of humpback whale calls and delphinid burst pulses similar to those found in this study area. DeepSqueak was shown to be the best tool for use in future analysis based on the investigations conducted for this Study. It provides a user-friendly interface for acousticians of varying experience to

[4] The Mann Whitney U test, sometimes called the Mann Whitney Wilcoxon Test or the Wilcoxon Rank Sum Test, is used to test whether two samples are likely to derive from the same population (i.e., that the two populations have the same shape). Some investigators interpret this test as comparing the medians between the two populations.

successfully detect calls in noisy environments. The scalability of the models allows for increased training with the introduction of new call types for each species or for use in a significantly different environment.

There were several observed trends in the detectability of the networks. The performance metrics clearly state the need to reduce false positives attributable to noise. Although noise initially resulted in a larger number of detections, false detections from noise decreased with increased training. Another challenging element to this effort was the occurrence of calls with a low signal to noise ratio. Calls with a lower signal to noise ratio (which were perceived as "very faint" by an acoustician) were less likely to be detected than those with a more discernible contour. Despite this, lower intensity calls could be detected, just not as frequently as calls with a higher signal to noise ratio. Therefore, calls of varying intensity were incorporated in the network development process. Through testing of the separate datasets, the performance of the deep neural network was robust when subjected to varying instrument and mooring noise as indicated by similar performance metrics.

The objective of this effort, to develop a deep neural network that successfully detects marine mammal sounds of interest and reduces detection of noise within a large passive acoustic dataset, was successful. In developing this network, a series of instructions with an associated instructional video were created. The first step involved working through the network training process within Ketos. A humpback whale network that performed well with the validation dataset was developed. The next step involved importing the network for evaluation of the test data in PAMGuard. Due to unresolved issues relating to the network configuration, it was not possible to import the network and efforts were therefore refocused on the second option using DeepSqueak. Two networks were developed: one for the detection of humpback whales and one for delphinids (predominantly burst pulse sounds). These networks were trained with a dataset of approximately 2,000 calls each. The training process started by importing Raven selection tables and underwent iterative training through review of detection files withing DeepSqueak. These steps are described in detail in **Appendix D** and in the accompanying video.

4.7.6.1 Ketos/PAMGuard Network

After working through the network training process within Ketos, a humpback whale network that performed well with the validation dataset was developed. The next step involved importing the network for evaluation of the test data in PAMGuard. Due to unresolved issues relating to the network configuration, the network could not be imported, and efforts were refocused on the second option. Although the completion of a network via this method did not occur, development is continuing. including coordination with PAMGuard developers to finalize the process of importing outside of this effort. The process is expected to be completed in the coming months.

4.7.6.2 DeepSqueak Network

Two networks were developed within DeepSqueak for detection of humpback whales. These networks were trained with a dataset of approximately 1,500 and 2,200 calls each, respectively. The call types used to train the networks consisted of the predominant call types that were found during the initial stage of this Study. Humpback whale calls from the BOEM deployment tend to be lower frequency (>1,000 Hz), tonal non-harmonic calls of short duration. The delphinid species encountered predominantly produced burst pulses and echolocation clicks. The burst pulses were selected as the signal for training the delphinid network. It should be noted that while the original intent was to develop a multi-species network that encompassed both species, it was determined that the large difference in frequencies for each call type would have resulted in spectrogram samples that were not representative of the humpback whale calls. Multi-species networks are possible when the calls occur within a similar bandwidth.

The training process started by importing Raven selection tables and underwent iterative training through review of detection files withing DeepSqueak. These steps are described in the instructions found in

Appendix D. Initially, programmatic issues occurred regarding low frequency call detection within DeepSqueak. A number of errors were resolved with several refinements and improvements under development.

Testing of the network resulted in the following average calculation of precision, recall, and F-score. These results are for the preliminary network and improved iteratively as the data used in the training were increased. Results were obtained through testing of three 30-minute files containing several hundred calls for each species and indicated that there is very little difference in the performance of this network on a secondary recorder, which is subject to different instrument and mooring related noise. Overall, the low precision for humpback whales is not unexpected due to the limited time available for improving the network, and also due to the large amount of noise in the dataset. However, recall metrics were comparable to some other studies using deep learning (Allen et al. 2021). The delphinid network performed better, largely due to the reduced noise above 10 kHz where most of the burst pulses were detected.

5 Discussion and Conclusions

This Study is the first of its kind to undertake an approach for assessing mechanical cutting noise in Pacific waters associated with removal of oil platform conductors. The findings are novel and precedent setting and provide a baseline for future comparisons as well as a foundation of data for use in impact evaluations for marine biological resources including marine mammals, fish, and sea turtles.

Some of the Study findings may be potentially useful in the assessment of potential impacts of future conductor cutting studies on marine mammals. The constraints of field work in the open ocean are well understood by marine contractors, researchers, and agencies with oversight on oceanic environments. Deploying equipment containing sensitive electronics at depth and pressure, subject to weather and unknowns in the deep sea, means any such real-time field efforts will have their limitations and risks. This was evidenced, for instance, by the failure of the NoiseSpotter hard drive. It is probable that redundancy in the equipment design (i.e., backup hard drives) would have mitigated the loss of data. Nonetheless, obtaining data in the open ocean via equipment deployment is challenging in the best of scenarios. This study was successful in obtaining recordings of cutting events, other secondary noise associated with the cutting processes, and in producing results and outputs giving a plethora of acoustic data findings and marine mammal call results.

5.1 Summary of Findings

A summary of the findings identified within the body of this report is provided below.

5.1.1 Environmental Conditions and Water Properties Summary

Wind and wave data were evaluated for the study period to determine if there were any significant events that would affect the acoustic data. During the study period, the wind speed ranged from approximately 1.6 m/s to 16.7 m/s with the peak occurring on April 10, 2021. Wave heights during the study period ranged from approximately 1 to 4 m (3 to 13 ft) with the peak occurring on April 10, 2021 as well. The wind and wave data do not identify any significant events that would cause any effect or significant influence on the acoustic data.

The thermistor chain was deployed at approximately 464 m (1,522 ft) from the edge of Platform Hermosa at an approximate depth of 193 m (633 ft). The data provide the sound speed profile over the duration of the study period. An approximately 1.5°C mean temperature gradient was observed, indicative of typical well-mixed winter waters with little stratification. Similar to temperature, mean sound speeds showed little variability over the measurement period, ranging from 1,487 to 1,490 m/s.

5.1.2 Ambient Noise Conditions Summary

A total of six acoustic recorders were deployed by Tetra Tech at five locations as described in Section 2.2.1. During the study period, continuous ambient data were not able to be collected before the start of the mechanical cutting or after completion of the cutting due to overall mechanical cutting duration at Platform Hermosa and logistics. However, there was a single approximately 29-hour period during which mechanical cutting did not occur and no vessel activity was within the Study monitoring area. This period occurred from 17:00 on April 9, 2021 to 00:30 on April 11, 2021. No significant events were identified during this period. However, noise generated from the platform was identified, but did not correlate with any mechanical cutting events. The ambient sound levels within the vicinity of the study area ranged from 114 dB SPL to 115.7 dB SPL at an approximate distance of 100 m (328 ft) from the edge of the platform. The ambient sound level at 250 m (820 ft) from the platform edge during this period was 112 dB SPL.

5.1.3 Mechanical Cutting Noise Level Results Summary

During the Study period, a total of 25 conductors were cut over 40 identified cutting events. The cut depth ranged from 6 to 8 m (20 to 25 ft) below the mudline and the cutter RPMs ranged from 60 to 72. The durations of the cuts were dependent on the number of casing strings that needed to be cut. Wellbores contain more casing strings and take much longer to cut compared to the conductors that are empty. In total, nine wellbores and 16 empty conductors were cut during the monitoring period. For comparison measurements from the acoustic monitor located closest (SoundTrap 5366) and furthest (SoundTrap 5353) from the platform were specifically reviewed and measured sound levels ranged from 120 to 130 dB SPL at the closest monitor to 114 to 124 dB SPL at the further monitor depending on the conductor being cut. The measured frequency spectrum of the wellbore cuts shows influence from the cutting operations from 25 to 5,000 Hz with a significant influence from 125 to 2,000 Hz.

The majority of wellbore conductors were cut at a depth of 20 ft below the mudline. Wellbore conductors B-1, B-9, and B-16 were cut at slight deeper depths of 22 to 25 ft below the mudline. Comparing these three wellbore conductors to the other six, the cutting depth does not appear to have a noticeable influence on the overall measured sound levels and spectrum. However, the variation in cutting depth is 5 ft or less and greater differences in cutting depths could result in a noticeable change.

Wellbore conductors B-9 and B-16 were the only conductors cut at a higher rate than 60 RPM; B-9 was cut using a higher RPM of 68 and B-16 used an RPM of 72. This change in RPM did not result in a noticeable difference to the sound levels or spectrum. Therefore, due to the limited amount of data collected during cutting at different RPM rates, no conclusions or trends can be identified from changing the RPM.

Sixteen empty conductors were monitored over the Study period. The empty conductors only required the outer casing to be cut, which resulted in much lower cutting times. For comparison measurements from the acoustic monitor located closest (SoundTrap 5366) and furthest (SoundTrap 5353) from the platform were specifically reviewed and measured sound levels ranged from 118 to 133 dB SPL at the closest monitor to 111 to 125 dB SPL at the further monitor depending on the conductor being cut. Similar to the wellbore cuts, the frequency spectrum of the empty conductor cuts shows influence from the cutting operations from 25 to 5,000 Hz. However, the significant influence extended over a broader frequency range from 32 to 2,500 Hz. The difference in the frequency range between the empty conductors and the wellbore conductors is likely due to the multiple casing strings within the wellbore conductors allowing less acoustic propagation.

Looking at only the mechanical cutting activities helps show the type of noise source within the water column. The mid-water column monitor (SoundTrap 5363) resulted in similar to slightly higher levels than the monitor on the same mooring located at the bottom (SoundTrap 5362). The consistent measured results at the mid-water column monitor with the monitor on the same mooring located at the bottom shows that conductor cutting noise was not only generated at the cutting location, but also up through the length of the conductor.

The empty conductor cuts were noted to be continuous and gradually increased until the end of the cut. Because this was an empty conductor, as the saw cut the conductor the noise slowly increased until the conductor was fully cut. This trend was identified for the majority of the empty conductor cuts. An example is given in section 4.3.1 where conductors S-4 and S-29 were evaluated and showed an approximate 10 dB increase in measured sound levels towards the end of the cut; however, this increase could vary based on the specific conductor being cut.

The sound generated by the cutting operations significantly increased the ambient sound levels in the vicinity of the platform. The wellbore cutting operations resulted in a 14 to 27 dB increase over the existing noise levels and the empty conductor cuts resulted in an increase of 18 to 33 dB over the existing noise levels.

In support of the conductor cutting operations, the M/V *Harvey Challenger* (Freeport's dynamically positioned supply vessel) was present for approximately 25 percent of the cutting events. The vessel indirectly supported the cutting operations by moving equipment and supplies. The influence of the vessel noise is apparent in the frequency ranging between 31.5 to 5,000 Hz; however, the contribution of conductor cutting activities is also observed in the frequency range of 250 to 800 Hz. The combined sound from the vessel and cutting operations ranged from 125 dB SPL at the acoustic monitor closest to the platform to 118 dB SPL at the acoustic monitor further from the platform. The SEL levels for the duration when both operations occurred range from 172 dB near the platform to 165 dB further from the platform. The sound measurement results with and without the contribution from vessel operations showed that vessel operations had a 1 to 4 dB influence on the SPL levels and a 3 to 5 dB influence on the SEL levels.

The noise data for all of the mechanical cuts were further evaluated for marine mammals by applying the NOAA Fisheries hearing weightings. The noise levels generated by the mechanical cutting activities were found to be well below the marine mammal PTS onset acoustic thresholds and generally below TTS onset acoustic thresholds.

5.1.4 Secondary Operational Results Summary

In addition to the mechanical cutting events identified in the logbook provided by Freeport, secondary operational events were also identified during the field program that generated noise levels. In conversation with Freeport, these secondary operational events correspond to activities prior and subsequent to actual mechanical cutting. These noise levels were significantly lower compared to the mechanical cutting with noise levels ranging from 130 dB SPL near the platform to 104.1 dB SPL at 250 m (820 ft) from the platform.

5.1.5 Azimuthal Variability Analysis Summary

The variability of acoustic radiation along an azimuth is the relative measure of acoustic energy propagating along a vertical plane in a single direction. Monitoring stations were placed on all four sides of the platform where the overall sound reduction in a single direction can be calculated. The reduction in each direction can then be compared to help determine the influence of obstacles (other conductors) in the path. Calculations to determine the azimuthal variability exhibited during conduct cutting were completed for four conductors on both the east and west sides of the platform. The results of the azimuthal variability analysis show that conductor-cutting noise emissions are affected by other conductors located between the cutting operation and monitor location. This reduction is shown to be as high as 4 dB when the cutting event occurs on the opposite side from the monitor location. The results of this analysis show there is an influence on the overall reduction as the cutting events get closer to the east side of the platform. After consulting with Freeport, it is understood that the diesel engine and pumps associated with the mechanical cutting were located on the east side of the platform near the vicinity of the conductor pipes. This likely influenced the azimuthal variability due to the influence of sound sources on the east side of the platform.

5.1.6 Sound Propagation Modeling Summary

Underwater sound propagation modeling was conducted to evaluate the noise propagation of a wellbore conductor and an empty conductor. Sound propagation modeling was completed using dBSea and the SPL frequency spectrum from SoundTrap 5366 was used as a source level. The duration of the event was also applied to calculate the SEL noise level for each event. The mechanical cutting was modeled as a line source based on the data trends previously discussed. The results of the model were then compared to the measurement results. The model noise results showed that the mechanical cutting activities do not generate noise levels high enough to exceed the thresholds for marine mammal permanent threshold shift onset. The marine mammal behavioral response distance ranges from 205 to 663 m (673 ft to 2,175 ft).

5.1.7 Marine Mammals Summary

The ability to detect calls from marine mammal species in the Study area despite the overwhelming contribution of noise from conductor cutting is a unique and meaningful finding. Passive acoustic monitoring (PAM) is a commonly used tool for determining the occurrence of marine mammals in a study area. Combining acoustic detections of marine mammals with visual observations increases the ability to monitor (and mitigate) as this allows for detecting animals under the water surface, at night or in inclement weather, or for cryptic species that are not generally active at the surface. As the field has grown, so too have the analytical capabilities for processing acoustic data including the use of computationally intensive calculations for determining soundscape metrics and enlisting deep learning methods for call detection and classification. The addition of acoustic analysis to our analytical effort illustrates that incorporation of PAM can contribute to the interpretation of several parameters including sound level exposure for these types of monitoring efforts.

During the three-week deployment, Tetra Tech found a significant contribution of sounds from humpback whales and from delphinid species. The calls from both humpback whales and delphinids occur within the same frequency bands as the conductor cutting noise. The majority of noise generated by conductor cutting activities occurred up to the 2 kHz frequency range although some influence could be observed beyond that level, up to approximately 10 kHz. Humpback whale calls predominantly occurred within a 200 Hz to 2 kHz bandwidth, and delphinid calls consisted mostly of burst pulses and echolocation clicks and spanned the 5 to 36 kHz bandwidth. The vocalizations of these animals were of a high enough amplitude that they were detected during periods of conductor cutting, suggesting the energy originating from calls could artificially increase the sound exposure level observed in the power spectral density analysis. This also suggests that the contribution of sound by marine mammals to the overall soundscape has implications for reported SELs.

Although the distance to vocalizing marine mammal groups was not possible to determine given the equipment configuration used for this Study, the detection of humpback whales calls indicates whales were likely within 10 km (5.4 nmi) of the platform during this Study. Similarly, the burst pulse calls from delphinids likely place them within 5 km (3 nmi) of the platform. Depending on the height of the platform, weather conditions, time of day, and other factors (e.g., sea state), these animals may or may not have been visually detectable by platform observers. It can be useful to have visual observers deployed in the field at the same time as acoustic data are being collected (especially if they are skilled at species identification) to validate acoustic detections obtained. The PAM results indicated that marine mammals were present in the general vicinity of the platform in April, which may provide baseline information, albeit limited to a small number of detected species, on the early spring distribution of these species within the general offshore localized region.

The consistent vocal activity of marine mammals within the region was of interest. Although Tetra Tech was not able to successfully evaluate behavioral changes to noise through an evaluation of changes in vocal activity, such evaluation may be possible in future studies with different PAM configurations and setups. Suggestions regarding future PAM methods are presented in recommendations in Section 6.

The results of the acoustic indices analysis provided insight into the dynamics of sound in this environment. Unfortunately, and likely as a result of the small sample size and close proximity to the platform, the indices evaluated did not yet show a useful relationship to marine mammal vocalizations or periods of conductor cutting noise. Although the statistical tests indicated significant differences in the soundscape metrics between periods with and without vocalizing marine mammals, the magnitude of these differences were trivial as indicated by the effect size calculations. A larger sample size (i.e., data collected over a longer period) at a slightly greater distance from the platform may yield more useful findings.

To date there is limited knowledge of how marine mammal sounds and noise influence acoustic indices measurements. This novel investigation demonstrated how confounding the metrics are when in close proximity to a site with large contributions of anthropogenic noise. A similar scenario emerged for the soundscape metrics in relation to periods with and without conductor cutting noise. While it is tempting to pursue use of these metrics for identifying periods with marine mammal or with cutting noise, the overall low effect size suggests they are not suited to this very noisy environment. The correlations matrix shown in Appendix C demonstrated that there were moderate to strong positive and negative relationships between the indices themselves and the few call variables used, but low to no relationships between the indices and call parameters. The ambient and anthropogenic noise sources appear to be too overwhelming to reflect the biological content in the data. However, evaluating these metrics at a farther distance from the platform would be helpful and would be expected to produce potentially more meaningful findings. If recorders were placed at a sufficient distance from the platform (approximately 1 km [0.8 mi]) so the noise does not overwhelm the recordings, then a more accurate assessment of their utility is possible.

As a supplementary passive acoustic endeavor, we sought to improve the efficiency and reliability of call detection within a noisy environment such as was found during this Study. Typically, review of acoustic data for marine mammal sounds is time consuming and requires an experienced analyst to parse true calls from noise. The objective of this supplemental analytical effort was to develop a deep neural network that successfully can identify marine mammal sounds of interest within a large passive acoustic dataset that was recorded a noisy environment. The network did this, it successfully recognized marine mammal vocalizations in a noisy environment which otherwise could have masked marine mammal calls and thus provides a useful tool for detection. Detection using a deep neural network is beneficial also in that it allows a novice analyst to review detections and classify accurate detections, especially as the classification capabilities of the network continue to learn. We effectively developed two deep neural networks that can be used for the detection of humpback whale calls and delphinid burst pulses similar to those found in this study area. The final selection of DeepSqueak as the tool for use in future analysis provides a user-friendly interface for acousticians of varying experience to successfully detect calls in noisy environments. Further, the scalability of the models allow for increased training with the introduction of new call types for each species or for use in a significantly different environment.

6 Recommendations for Future Work

This section summarizes Tetra Tech's recommendation for the various analyses investigated in the course of this Study. Recommendations are given for future studies based on lessons learned from the current field program and resultant measurement data. These suggestions are offered as suggested refinements that could potentially be incorporated into future, similar conductor-cutting events to provide additional data that would build upon the findings of this initial study.

Future Acoustic Studies

1. Mechanical Cutting Activities:
    a. The results of the Study provided sufficient data for mechanical cutting activities for the specific operational conditions observed including the typical cutting depth of 20 ft below the mudline and conductor cutting RPM of 60; however, additional field measurements would be recommended to capture operational conditions beyond those observed for this Study.
2. Refinement of Field Effort Logistics:
    a. Ensure the platform contractor tracks and provides detailed cutting data, times, durations, and intervals in a timely manner to the acoustic data scientists for accuracy in tracking cutting events.
    b. Have trained staff onsite during conductor-cutting activities and field monitoring instructed to be a Point of Contact to communicate with the acoustic analysts, in order for the analysts to better understand the cutting activity process, machinery, and vessel movements and how those factors might influence resultant monitoring data.
    c. Increase the deployment duration to include additional time before and after the conductor-cutting operation to better characterize ambient acoustic conditions. This would further assist in identifying cutting activities as well as calls from marine species.
    d. Additional field monitor design would be recommended. Station a recorder or recorders farther away from the platform. For instance, having one set of three receivers (or similar) along at least a single azimuth in order to better characterize the transmission loss plot would be recommended. Placing the recorders farther away would reduce interference from vessel operations. Also, place monitors at different water depths to better characterize the sound in the water column.

Future Particle Motion Studies:

1. It is strongly recommended that any future particle motion equipment add in a redundant hard drive to collect parallel data streams as opposed to deploying equipment with only a single hard drive. This redundancy would prevent the total loss of data if one hard drive fails.
2. In addition, physically protecting and buffering the hard drive from impact would increase the chances of successful data acquisition. The solid state hard drive used in this Study was clearly subject to some kind of impact. Despite repairs ongoing for 11 months, the hard drive has not been able to be repaired, although efforts continue.

Future Marine Mammal and/ or Sea Turtle Study Recommendations including for Passive Acoustic Studies:

1. Expand upon the existing study design by incorporating a formal marine mammal monitoring program, which could include monitoring for sea turtles. In order to validate the passive acoustic monitoring data, and expand species detection, it is recommended that future studies include experienced, independent protected species observers. Also, to better understand the potential impacts to protected species, as well as their occurrence and distribution, we recommend

expanding the data collected and provided by the observers. We suggest the data collection forms be re-designed to include the following minimal data entries:

a. Sighting start time and end time
b. Sighting occurred using binoculars or naked eye
c. Distance of species from cutting site
d. Estimated group size of observed whale(s), dolphin(s) or sea turtle(s) (low, medium, and high estimate)
e. Estimated age class (adult, juvenile, calf)
f. Any distinguishing characteristics (blow height, coloration, dorsal fin shape, scars)
g. Best guess of species identification
h. Behavior (travel, surface, active, mill, rest)
i. If travel: direction of travel
j. Photos: yes/no, photographer name

2. Consider the use of an independent vessel stationed in proximity to the platform as a station for the protected species observers.

3. PAM was proven successful in detecting marine mammals not sighted visually during conductor cutting. Incorporating additional acoustic monitoring into future cutting studies is recommended. This study verified that marine mammal occurrences can be detected during conductor cutting if animals are calling. In future work, additional PAM focus is recommended.

4. Ideally, future efforts would include use of time-synchronized recorders to allow for localization of vocalizing marine mammals. Being able to supply details on species presence and location would also provide a baseline for assessing if they are avoiding the area due to noise produced by cutting. (One possibility is the SonarPoint system[5] developed by Desert Star Systems, which is a portable set of hydrophones that have localization capabilities.)

5. The addition of deeper water recorders would also increase the capacity to pick up other species (e.g., sperm whales or beaked whales).

6. Consider designing a subsequent BOEM study to more accurately assess the following: a) determine the location and distance of marine mammals detected by PAM from the platform; and b) monitor the response of individual marine mammals detected by PAM to conductor cutting activities (ideally stratified by distance from platform and SPL level). BOEM could use the information derived from this type of study that includes these types of supplemental analyses, in conjunction with acoustic and particle motion data, to develop an appropriate and effective observation and monitoring protocol. Combining visual and acoustic monitoring is a well-accepted practice for marine mammal monitoring.

7. At a minimum, future conductor-cutting operations should put an enhanced focus on marine mammal monitoring via the use of hydrophones placed at closer and farther distances from cutting sites than was done in this pilot study.

8. Conduct focal species studies.

9. Monitoring a wider bandwidth that accommodates the upper end of the MF hearing group would allow for other species detections. For example, MF species include beaked whales. Other studies have shown beaked whales could potentially be influenced by anthropogenic noise (Manzano-

[5] https://www.desertstar.com/sonarpoint

Roth et al. 2016; Cholewiak et al. 2017). For an example from this study area within the Southern California region, Baird's beaked whale (*Berardius bairdii)* have a multi-peak structure to their echolocation clicks at frequencies of approximately 9, 16, 25, and 40 kHz (Baumann-Pickering et al. 2013). The lower end of these clicks falls within the noise range contributed by conductor cutting. Since echolocation clicks from this species contain energy above the upper end of the bandwidth recorded during this Study (i.e., 36 kHz), a greater bandwidth is needed to correctly classify acoustic events as belonging to Baird's beaked whales.

Future Indices Studies:

1. Refinement of Indices Evaluations. The acoustic indices analysis did not result in a predictive correlation for biophony or anthrophony in this dataset. However, in testing of their use as indicators of periods of noise or marine mammal vocal activity, the measurements were found to be confounded by overwhelming noise from the platform activities. Such measurements may still be useful if the recorders were located farther from the platform so that more subtle differences in acoustic measurements are possible. Stationing a recorder or recorders far from the platform (e.g., 2 to 3 km [1 to 1.5 nmi]) away but still within the study area) could provide insight into the utility of these acoustic indices for efficient monitoring of marine mammals. This would in turn assist in developing the sound propagation model and provide a better opportunity to demonstrate the existence of strong relationships to biophony or anthrophony. Marine mammal calls can be detected within this distance and this separation would provide a buffer from overwhelming platform noise.
2. Recommendations for more user training and data collection for neural network improvement. The DeepSqueak networks that were developed for humpback and delphinids could be improved from additional training in order to increase performance. DeepSqueak is beneficial to use in that it is user friendly and easily improved upon using the instructions found in these results. The objective of this effort was not to perfect these networks, so additional training is advised.
3. Collecting additional data in the area is recommended to improve the detection of additional call types that these animals produce. Additionally, incorporating noise samples from the dataset being analyzed should reduce the number of detections attributable to noise. Development of these models involved simultaneously working through programmatic changes to DeepSqueak to improve performance, and refinement of the program has continued after the end of the Study. Leveraging those modifications with additional model training after improvement of the software is recommended.

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