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FY23 Annual Report on Pacific Missile Range Facility Marine Mammal Monitoring

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14. ABSTRACT
EXECUTIVE SUMMARY
This report documents the Naval Information Warfare Center (NIWC) Pacific Whale Acoustic Reconnaissance Project (WARP) Laboratory's marine mammal monitoring efforts in fiscal year (FY) 2023 for Commander, Pacific Fleet (COMPACFLT) at the Pacific Missile Range Facility (PMRF), Kaua‘i, Hawai‘i. The following list highlights tasks completed in FY23 in support of COMPACFLT monitoring goals:
•Raw acoustic data from 63 bottom-mounted hydrophones at PMRF were recorded at a sampling rate of 96 kHz. This report updates last year's report with inclusion of 6,150.1 hours of new data collected and analyzed from August 2022 to August 2023 for FY23.
•Abundance results for baleen whales for FY23 are presented using the mean number of whale tracks present in 2.5-minute snapshots per hour and for each month. Processed results for the highest monthly mean number of baleen whales were: minke (1.25 in March 2023); humpback (0.19 in January 2023); sei (0.20 in January 2023); fin (0.58 in December 2022); Bryde's (0.16 in October 2022); 20-Hz downsweep fin/sei category (0.10 in January 2023); and 40-Hz downsweep fin/sei category (0.12 in January 2023). Automatically detected and localized blue whales calls were manually verified in January 2023 on the 3rd, 6th, 11th, 15th, and 16th.
•Hidden Markov models (HMMs) were used to identify two kinematic states (slower, less directional movement and faster, more directional movement) in 150 acoustically derived Bryde's whale tracks from recordings spanning the years 2011–2022 with recording effort in nearly every month. The findings indicate that Bryde's whales were more likely to

travel in a faster and more directional state during the daytime than at night and between May and August when compared to other times of year. The along-track acoustic cue rate was examined for 118 tracks, and the findings indicate a possible lengthening of the median call interval over the duration of the study period.

•Abundance results of group vocal periods for odontocetes from August 2022 to August 2023 included Blainville's, Cuvier's, Cross Seamount beaked whales, killer whales, and sperm whales, and for the first time, Longman's beaked whales. The highest group vocal period (GVP) rate of Blainville's beaked whales was 4.2 GVPs/hour in June 2023. The Cuvier's, Cross Seamount, and fully validated Longman's beaked whale GVPs occurred far less frequently than Blainville's beaked whale GVPs, resulting in a maximum of 0.17 GVPs/hour in March 2023 for Cuvier's beaked whales, 0.31 GVPs/hour for Cross Seamount beaked whales in August 2022, and 0.13 GVPs/hour in June 2023 for Longman's beaked whales. Killer whales were detected throughout the available FY23 data and 11 manually validated groups occurred. The highest mean number of sperm whale groups in all 2.5-minute snapshots in a month was 0.58 in November 2022.

•During the February 2023 Submarine Command Course (SCC) a total of nine tracked whales were exposed to MFAS. Four fin and two humpback whales were exposed to sonobuoy transmissions only, one fin and one humpback whale were exposed to surface ship transmissions only, and one humpback whale was exposed to surface ship, sonobuoy, and helicopter dipping sonar transmissions. The highest median received levels by source were estimated with propagation modeling: 95.0 dB re 1μPa (sonobuoy), 120.7 dB re 1μPa (helicopter dipping sonar), and 159.0 dB re 1μPa (surface ship hull-mounted sonar).

•Group foraging dive rates for Blainville's, Cuvier's, and Cross Seamount beaked whales were analyzed before, during, and after the February and August 2023 SCCs. In February, all beaked whales exhibited a decrease in GVPs/hour from the Before period to Phase A of the SCC, a slight increase in the non-exposure period after Phase A and before Phase B (i.e., Between), a further reduction in Phase B of the SCC (with the exception of Cuvier's beaked whales), and a slight increase in the After period. The phases of the August 2023 SCC were discontinuous, however, a similar overall trend was apparent with depressed GVPs/hour during both phases of the SCC and with recovering GVPs/hour in the After period.

•Sounds suspected to be associated with fish chorusing and the Deep Scattering Layer (DSL) upward daily vertical migration were observed occurring daily over 12 days of data in January 2017. The sounds occur from 1.4 to 1.8 kHz with the peak near 1,650 Hz. They are detectable on multiple broadband hydrophones (21 to 68 km offshore) in deep water (1.5 to 4.7 km), suggesting a large spatial extent. The maximum spectrum level in the 1.6 kHz one-third octave band observed to date is 71 dB re 1 μPa2/Hz.

15. SUBJECT TERMS
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- Abundance results for baleen whales for FY23 are presented using the mean number of whale tracks present in 2.5-minute snapshots per hour and for each month. Processed results for the highest monthly mean number of baleen whales were: minke (1.25 in March 2023); humpback (0.19 in January 2023); sei (0.20 in January 2023); fin (0.58 in December 2022); Bryde's (0.16 in October 2022); 20-Hz downsweep fin/sei category (0.10 in January 2023); and 40-Hz downsweep fin/sei category (0.12 in January 2023). Automatically detected and localized blue whales calls were manually verified in January 2023 on the 3rd, 6th, 11th, 15th, and 16th.
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- Abundance results of group vocal periods for odontocetes from August 2022 to August 2023 included Blainville's, Cuvier's, Cross Seamount beaked whales, killer whales, and sperm whales, and for the first time, Longman's beaked whales. The highest group vocal period (GVP) rate of Blainville's beaked whales was 4.2 GVPs/hour in June 2023. The Cuvier's, Cross Seamount, and fully validated Longman's beaked whale GVPs occurred far less frequently than Blainville's beaked whale GVPs, resulting in a maximum of 0.17 GVPs/hour in March 2023 for Cuvier's beaked whales, 0.31 GVPs/hour for Cross Seamount beaked whales in August 2022, and 0.13 GVPs/hour in June 2023 for Longman's beaked whales. Killer whales were detected throughout the available FY23 data and 11 manually validated groups occurred. The highest mean number of sperm whale groups in all 2.5-minute snapshots in a month was 0.58 in November 2022.
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ACRONYMS

AIC	Akaike information criteria
BWC	Cross Seamount beaked whale signal
COMPACFLT	Commander, Pacific Fleet
CRAWL	Continuous-time correlated random walk model R package
CRC	Cascadia Research Collective
DASBR	Drifting Acoustic Spar Buoy Recorder
DCL	Detection classification localization
DSL	Deep scattering layer
FY	Fiscal year
GPL	Generalized power law
GVP	Group vocal period
HFM	High-frequency modulated
HMM	Hidden Markov model
ICI	Inter-click interval
LAT	Localization association tracker
LMR	Living Marine Resources Program
MFAS	Mid-frequency active sonar
NIWC Pacific	Naval Information Warfare Center Pacific
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
PAM	Passive acoustic monitoring
PIFSC	Pacific Islands Fisheries Science Center
PMRF	Pacific Missile Range Facility
SCC	Submarine Command Course
TRACKEX	Tracking Exercise
UH	University of Hawaiʻi
US	United States
WARP	Whale Acoustic Reconnaissance Project

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1. INTRODUCTION

In fiscal year (FY) 2023, the Naval Information Warfare Center (NIWC) Pacific Whale Acoustic Reconnaissance Project (WARP) Laboratory (San Diego, California) utilized passive acoustic data recordings from bottom-mounted range hydrophones at the Pacific Missile Range Facility (PMRF), Kaua'i, Hawai'i to monitor vocalizing cetaceans both during baseline periods and during United States (US) Navy training activities.

The FY23 goals of this ongoing effort were to:

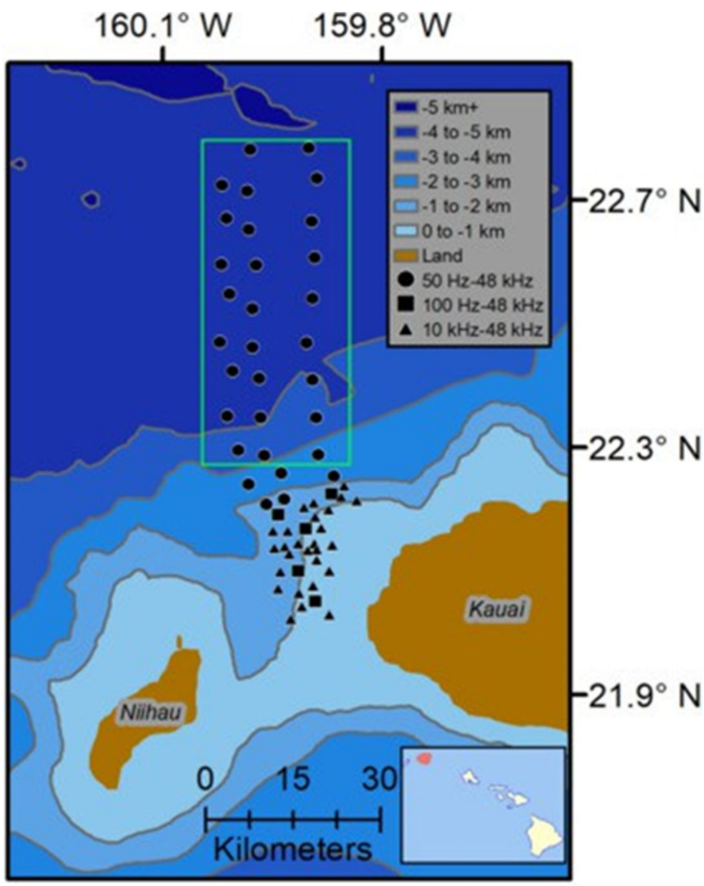
- Collect raw acoustic data for cetacean species detection, classification, localization (DCL), tracking, and perform movement and acoustic cue rate analyses;
- Understand short-term baseline occurrence patterns and quantify minimum (snapshot) abundance estimates for multiple cetacean species;
- Continue to update our processing algorithms in order to add new species, improve existing tools, and integrate additional tools as available;
- Estimate sound levels received by cetaceans during US Navy training with mid-frequency active sonar (MFAS) from multiple sources;
- Investigate potential behavioral responses to sound exposures as well as vessel presence and movement for tracked whales, and investigate changes in dive rates across training phases for beaked whales; and
- Collaborate with researchers conducting other monitoring efforts (e.g., MFAS exposure and response by tagged animals) – including other US Navy laboratories, academic institutions, and research organizations – to fill data gaps and provide a more complete monitoring data product.

This report also highlights specific analyses that were conducted to support publication of peer review papers in FY23 in pursuit of the above goals. These include major improvements to our tracking algorithms to be able to visualize the along-track calls for species verification; a long-term analysis of Bryde's whale movement patterns and acoustic cue rates; an analysis of a period of ambient noise that may include signals from the deep scattering layer (DSL); a behavioral response analysis of acoustically tracked whales to multiple sources of MFAS, including hull-mounted, sonobuoy, and helicopter-dipping; and a first look at sei whale tracks resulting from the improvements to the tracking tool.

2. Methods

2.1 PMRF RANGE DATA

Passive acoustic monitoring (PAM) data were recorded for 63 of the PMRF bottom-mounted hydrophones (Figure 1) to support analyses of marine mammal vocalizations and MFAS transmissions. Full-bandwidth (96 kHz sampling rate) recordings were conducted from August 2022 through August 2023.



- The green box outlines the approximate boundary offshore Kaua'i, Hawai'i (shaded red in the inset map) for tracking whales in data collected from August 2022 to August 2023.

Figure 1. Hydrophone array configuration at PMRF's instrumented range for data collected August 2022 to August 2023.

2.2 NAVY ACOUSTIC RANGE WHALE ANALYSIS ALGORITHM SUITE

2.1.1 Automated Detection, Classification, Localization, and Tracking Algorithms

A suite of several algorithms called the Navy Acoustic Range Whale Analysis (NARWHAL) suite was used to process recorded data and was previously described in Helble et al. (2012, 2015, 2016, 2020a); Henderson et al. (2016, 2018a); Manzano-Roth et al. (2016), and Martin et al. (2015). As a brief review, one custom C++ algorithm automatically detects and classifies two types of baleen whale vocalizations (minke whale boing calls and low-frequency downsweep calls that could be attributable to Bryde's, sei, fin, or blue whales), six odontocete vocalizations (Blainville's, Cuvier's, Longman's, and Cross Seamount beaked whale clicks, sperm whale clicks, and killer whale high-frequency modulated (HFM) signals), and MFAS transmissions. A second C++ algorithm localizes detected baleen whale calls, sperm whale clicks, and MFAS transmissions. After localization, a localization association tracker (LAT) algorithm in Matlab (Klay et al., 2015) uses spatial and temporal parameters based on general calling rate expectations for different species to connect localizations into tracks. A separate Matlab Generalized Power Law (GPL) algorithm detects and localizes humpback whale song, certain types of blue whale calls, and low-frequency calls. Based on the results of the GPL algorithm, a human analyst manually reviews spectrograms of the data and call intervals along the track to examine call characteristics and patterns to classify low-frequency localizations as fin whale song, Bryde's whale calls, and non-specific categories of 20-Hz and 40-Hz downsweeps (possibly attributable to fin, sei, or blue whales). Fin whale tracks presented in this report are comprised of tracks from the fin whale song and non-song categories. There is also an "unknown" category that encompasses signals grouped into tracks that correspond to unfamiliar signals which could be biologic or non-biologic in nature. These may be used for reference in future analyses and investigations but are not presented in this report.

Whale track abundance results (Section 3.2.1 to Section 3.2.14) are presented as the mean number of whale tracks during an instantaneous snapshot every 2.5 minutes. An instantaneous snapshot looks at a point in time and if it is within the start and end times of a track, the track is counted in that snapshot. For whale track snapshot results, the monthly mean values may be lower than the hourly mean values due to the occurrence of snapshots with zero tracks, which are factored into the monthly mean. Systematic snapshots of whale tracks enable a census-type abundance estimate for calling whales that can be localized and tracked. For individual whale track results presented under Section 3.2, a study area of ~1,200 km^2 (22.8°to 22.275°N-S and -159.85°to -160.05°E-W) that encompasses the hydrophone array was used for tracking minke, sei, and sperm whales (Figure 1). Because of differences in the localization algorithm, tracks generated by the separate Matlab GPL algorithms (attributed to fin, Bryde's, and humpback whales and those composed of 20-Hz and 40-Hz downsweeps) were grouped into tracks using a large study area spanning about one degree of latitude and longitude centered on the PMRF array (23.1°to 22.0°N-S and -160.5°to -159.5°E-W).

Beaked whale clicks and killer whale HFM signals cannot currently be localized at PMRF due to a combination of the directionality and frequency of the calls and the distance between hydrophones, but another Matlab-based algorithm was used to group those vocalizations when they occurred on neighboring hydrophones within a certain timeframe. Beaked whales emit echolocation clicks at depth while they are diving with other group members; therefore, groups of their clicks are referred to as group vocal periods (GVPs), which are used here to quantify abundance. A subset of Blainville's, Cuvier's, Longman's, and Cross Seamount beaked whale GVPs were randomly selected and manually validated using the raw acoustic data. Killer whale HFM signals were also grouped by this algorithm when they occurred close enough in space and time. All such groups were manually validated due to their rarity at PMRF. Co-occurrences of HFM signals are simply referred to as groups.

Relative abundance estimates based on track snapshots and GVPs are constrained by the number of animals vocalizing, which can depend on life stage, sex, and behavioral state. Cue rates and intraspecies proximity (relative to localization precision) are also confounding factors. These metrics therefore correspond to a minimum density of vocalizing animals in the study area. As with any PAM analysis, population abundance estimates require additional baseline population information, including the ratio of calling animals to all animals. For odontocetes that cannot be localized but emit vocalizations based on foraging (such as echolocation in beaked whales), group dives could be converted to a minimum density estimate if the average group size were known and relatively stable.

2.2.1 Improvements to Processing Algorithms

This FY, rather than combine tracks manually classified as fin song and ambiguous fin/sei whale calls into one "fin" category, the ambiguous fin/sei calls — which look similar to fin B note downsweeps but occur at slightly higher and more variable center frequencies and do not seem to occur at a regimented call interval the way fin song does (Figure 2) — are reported in their own 20-Hz downsweep category.

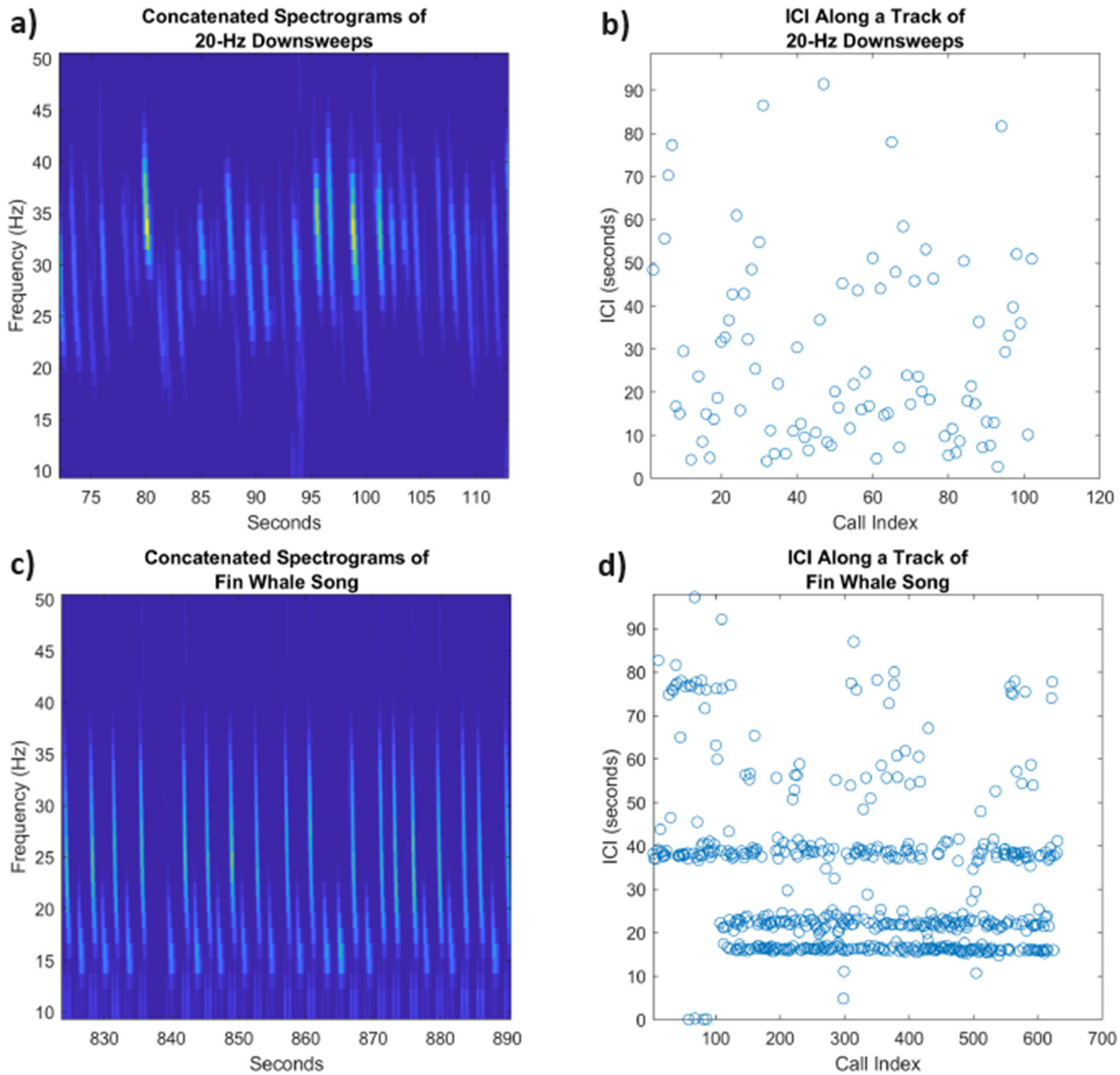


Figure 2. Comparison of low-frequency downsweep calls from a track comprised of 20-Hz downsweeps belonging to an unknown baleen whale (panels a and b) to a track of fin whale song composed of A & B calls (panels c and d). The unspecified 20-Hz downsweeps are slightly higher and more variable in center frequency and bandwidth (panel a) than fin whale B calls (panel c) and the call interval is far less regimented (panels b and d).

Tracks of low-frequency baleen whale downsweeps produced by the C++ algorithms, which have previously precluded easy manual validation, are usually presented as this general category of "low-frequency baleen whales", supplemented by the more specific and manually validated products from the Matlab GPL algorithms. This FY, as part of the LMR effort assessing Bryde's whale swimming behavior and acoustic cue rates, a tool was developed to allow manual validation of low-frequency baleen whale tracks produced by the C++ algorithms. Consequently, for the first time confirmed sei whale tracks— based on published spectrograms and information on call characteristics, such as their tendency to occur in pairs and sometimes triplets (Baumgartner et al., 2008; Español-Jime´nez et al., 2019; Rankin and Barlow, 2007) — on PMRF are presented in Section 3.2.3. Example calls from a track classified as sei are shown in Figure 3. The manual validation tool for the tracks produced by the Matlab GPL algorithms is currently constrained by a limited bandwidth, so these sei whale tracks likely appear in the more ambiguous 40-Hz downsweep category for those algorithms.

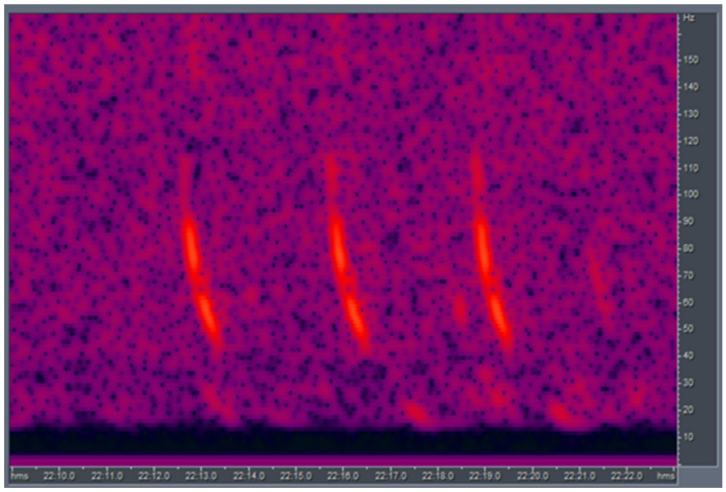


Figure 3. Example spectrogram of a triplet of low-frequency downsweeps from a track classified as a sei whale.

Information about Longman's beaked whale presence is also presented this FY for the first time. The new beaked whale classifier that includes Longman's beaked whale clicks is preliminary and still requires some adjustment to minimize false positives for all beaked whale species, but there were few enough Longman's beaked whale detections when tested on this FY's data to accommodate complete manual validation. This new classifier was not run on data from the SCC periods. The results for the other beaked whale species were produced by the legacy classifier to maintain consistency with previous years while this new classifier is further developed.

Updates were also made to the Matlab algorithm that automatically associates beaked whale clicks into GVPs based on spatial and temporal proximity to attempt to better accommodate complex situations, such as when two GVPs co-occur or when a false positive (e.g., a delphinid click) interferes with the timing of an attempted GVP.

2.2.2 Behavioral Response Analysis

The Behavioral Response Analysis process investigates whether whale presence overlaps with and is affected by anthropogenic activities. Received levels from MFAS transmissions from surface ship hull-mounted sonar, helicopter dipping sonar, and sonobuoys are estimated, in addition to the proximity of ships even when not transmitting MFAS. The result is an opportunistic passive acoustic behavioral response study to US Navy platforms and sources during training activities. This is accomplished using MFAS localizations, which have been a longstanding output from the C++ algorithm suite, combined with platform location information provided in PMRF range data products. When overlap occurs with whale tracks, a variety of metrics are calculated/estimated such as whale orientations (i.e., moving towards or away from the source), ship orientations relative to the whale, and distances relative to all ships. When sources are transmitting sonar, propagation modeling is conducted to calculate received sound levels at each individual over the duration the whale was acoustically active.

2.2.3 Noise Analyses

The primary goals of conducting noise analyses on PMRF acoustic data are to better understand how PAM processing results are affected by noise levels and to assess vocal behavioral changes relative to environmental noise levels (Helble et al., 2020b; Guazzo et al., 2020). The noise analyses characterize noise in relevant frequency bands of interest to look for changes in noise over a wide variety of spatial and temporal scales, and to assess any impact these changes may have on detecting and localizing marine mammal vocalizations. Results from noise analyses are also utilized for internal purposes to identify data dropouts or suspicious "unnatural" noise readings that could affect recording effort. The noise results are also used to look for long-term trends in changes in ambient noise. For FY23 we focused our noise analysis on sounds that were suspected to be from fish chorusing (Section 3.2.15).

For a noise analysis, recorded data are processed to provide spectrum-level measurements for selected hydrophones. The spectrum-level energy is also integrated over targeted frequency bands of interest, such as the processing bands used for call detection. These integrated noise band levels include all sources of sound in the ocean (e.g. species calls, environmental noise, and anthropogenic sounds).

3. Results and Discussion

3.1 PMRF RANGE DATA COLLECTION RESULTS

The FY23 data processed for this report spanned August 29, 2022 to August 24, 2023. A total of 6,150.1 hours of data were recorded which includes 270.3 and 239.2 hours of classified data collected during the February and August SCC training events, respectively (Table 1). This is the most data recorded and analyzed during an annual performance period to date for this project and an increase from 5,395.6 hours recorded for the FY22 dataset.

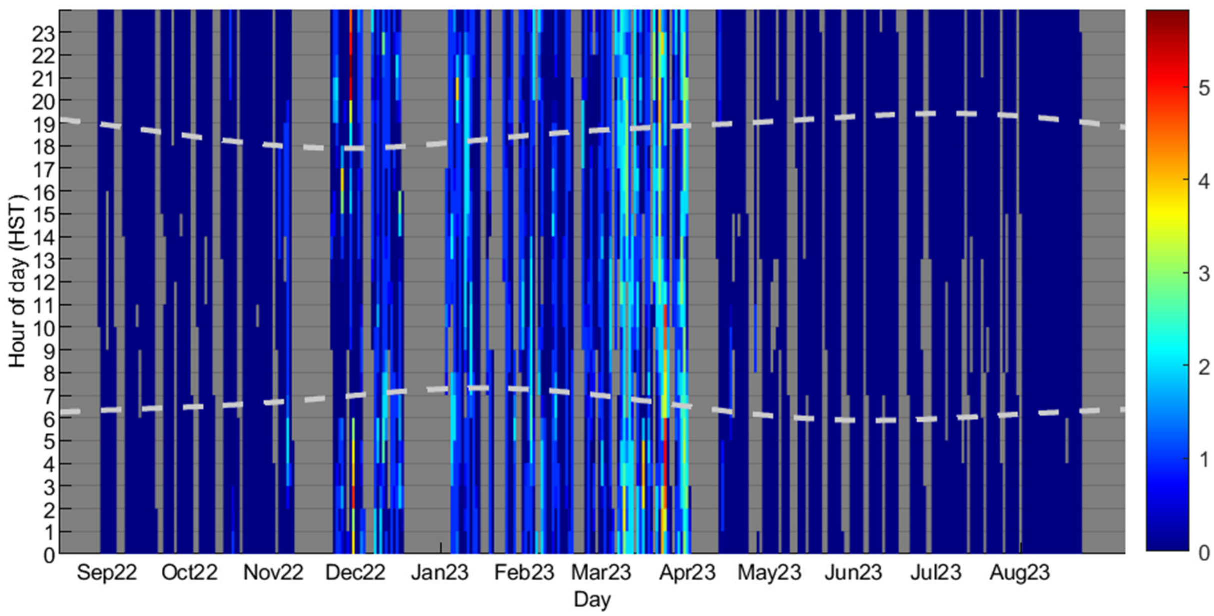
Table 1. Total monthly hours of recording effort for FY23 data (August 2022 to August 2023).

Month	Hours	% of Time Recorded
August-22	51.8	7
September-22	542.1	75
October-22	569.2	77
November-22	336.3	47
December-22	345.7	46
January-23	444.2	60
February-23	540.7	80
March-23	612.5	82
April-23	355.5	49
May-23	524.2	70
June-23	535.4	74
July-23	626.7	84
August-23	530.4	71
Total	6,150.1	65

3.2 ABUNDANCE AND DISTRIBUTION

3.2.1 Minke Whales

The mean number of automatically tracked, individual calling minke whales in 2.5-minute snapshot periods from all recordings made between August 2022 and August 2023 are presented per hour in Figure 4 and per month in Table 2. Seasonal presence typically lasts from fall to winter. Minke whales were present starting from October 2022 to April 2023. Mean monthly presence was highest in March 2023 (1.25 whales/snapshot) and was elevated from December 2022 to March 2023. A peak hourly mean of 5.83 whales/snapshot occurred once in November, and hourly means were ≥5 whales/snapshot in a total of five one-hour bins — three times in November 2022 and twice in March 2023. For comparison, in the FY22 annual report (Martin et al., 2023) minke whale acoustic presence occurred from November 2021 to April 2022, so the 2022–2023 season was slightly longer. Peak monthly presence last season occurred in February and was elevated from December 2021 to March 2022; this was comparable to this year, but with a slightly earlier peak month in 2022. Also similar to this year, a peak hourly mean of 5 whales occurred twice in November 2021 and once in March 2022.



- Dark blue regions indicate periods of effort when acoustic recordings were collected and zero whale tracks were present. Results include classified data collected in February and August 2023. Gray shaded regions indicate periods of no recorded data. The light gray dotted lines indicate sunrise and sunset times.

Figure 4. The mean number of minke whales detected in 2.5-minute snapshot periods for each hour of the day from August 2022 to August 2023 ranged from 0.04 (blue) to 5.83 (dark red).

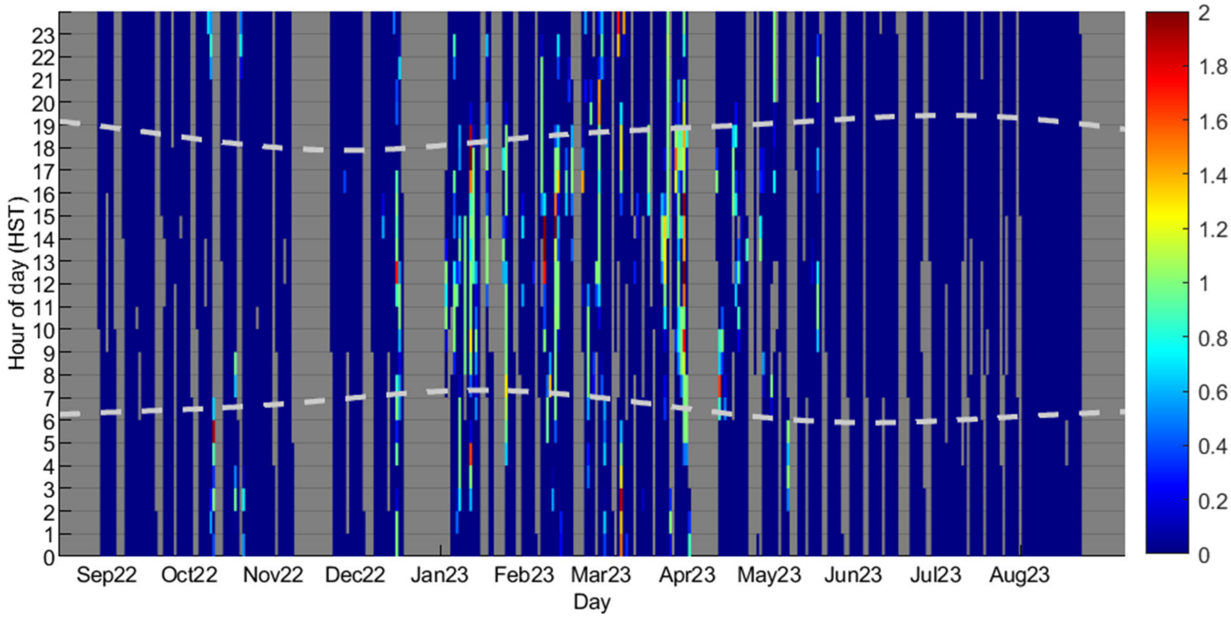
Table 2. Monthly numbers of minke whales detected in 2.5-minute snapshots.

Date	Number of Snapshots	Mean Snapshot	Standard Deviation
August-22	–	–	–
September-22	–	–	–
October-22	3,253	0.04	0.20
November-22	7,191	0.45	0.97
December-22	8,295	0.56	0.65
January-23	10,651	0.68	0.66
February-23	11,701	0.52	0.62
March-23	14,691	1.25	1.03
April-23	4,517	0.42	0.84
May-23	–	–	–
June-23	–	–	–
July-23	–	–	–
August-23	–	–	–

3.2.2 Humpback Whales

The mean number of automatically tracked, individual calling humpback whales in 2.5-minute snapshot periods from all recordings made between August 2022 and August 2023 are presented per hour in Figure 5 and per month in Table 3. Humpback whales were present from October 2022 to May 2023. Mean monthly presence was highest in January 2023 (0.19 whales/snapshot), and elevated in March 2023 (0.17 whales/snapshot). There was a peak mean of 2.00 whales/snapshot detected in a one-hour bin, once in January 2023, three times in February 2023, and once in March

2023. For comparison, in the FY22 annual report (Martin et al., 2023) humpback whale seasonal presence occurred at the same time as this year, from October 2021 to May 2022. Mean monthly presence was highest in February 2022, and a peak hourly mean of 3 whales occurred once in February 2022, whereas this year the peak was slightly lower and occurred earlier in January.



- Dark blue regions indicate periods of effort when acoustic recordings were collected and zero whale tracks were present. Results include classified data collected in February and August 2023. Gray shaded regions indicate periods of no recorded data. The light gray dotted lines indicate sunrise and sunset times.

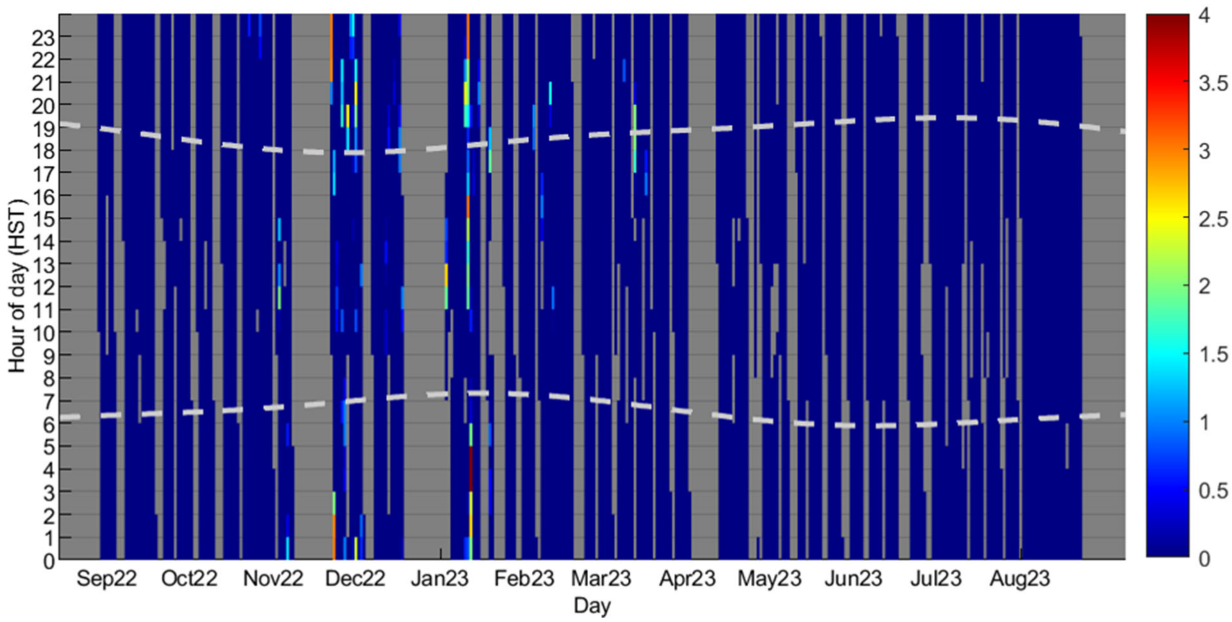
Figure 5. The mean number of humpback whales detected in 2.5-minute snapshot periods for each hour of the day from August 2022 to August 2023 ranged from 0.04 (blue) to 2.00 (dark red).

Table 3. Monthly numbers of humpback whales detected in 2.5-minute snapshots.

Date	Number of Snapshots	Mean Snapshot	Standard Deviation
August-22	–	–	–
September-22	–	–	–
October-22	6,797	0.05	0.23
November-22	2,885	0.003	0.06
December-22	5,234	0.09	0.30
January-23	9,610	0.19	0.42
February-23	12,127	0.13	0.38
March-23	12,833	0.17	0.42
April-23	7,765	0.11	0.35
May-23	5,636	0.06	0.24
June-23	–	–	–
July-23	–	–	–
August-23	–	–	–

3.2.3 Sei Whales

Sei whales were detected and classified from the C++ algorithms for the first time this FY. The mean number of automatically tracked sei whales detected in a 2.5-minute snapshot period from August 2022 to August 2023 are reported for each hour of the day in Figure 6 and by month in Table 4. Sei whales were detected on the PMRF range from October 2022 through March 2023. Their peak occurred in January 2023 with a maximum of 4 and a mean of 0.20 whales/snapshot. The hourly mean whales/snapshot also peaked in January with 4.00 whales/snapshot. November had the next highest number of tracks, with a maximum of 4 and a mean of 0.13 whales/snapshot. The mean rate of whales/snapshot in the rest of the season varied between 0.01 and 0.07.



- Dark blue regions indicate periods of effort when acoustic recordings were collected and zero whale tracks were present. Results include classified data collected in February and August 2023. Gray shaded regions indicate periods of no recorded data. The light gray dotted lines indicate sunrise and sunset times.

Figure 6. The mean number of sei whales detected in 2.5-minute snapshot periods for each hour of the day from August 2022 to August 2023 ranged from 0.04 (blue) to 2 (dark red).

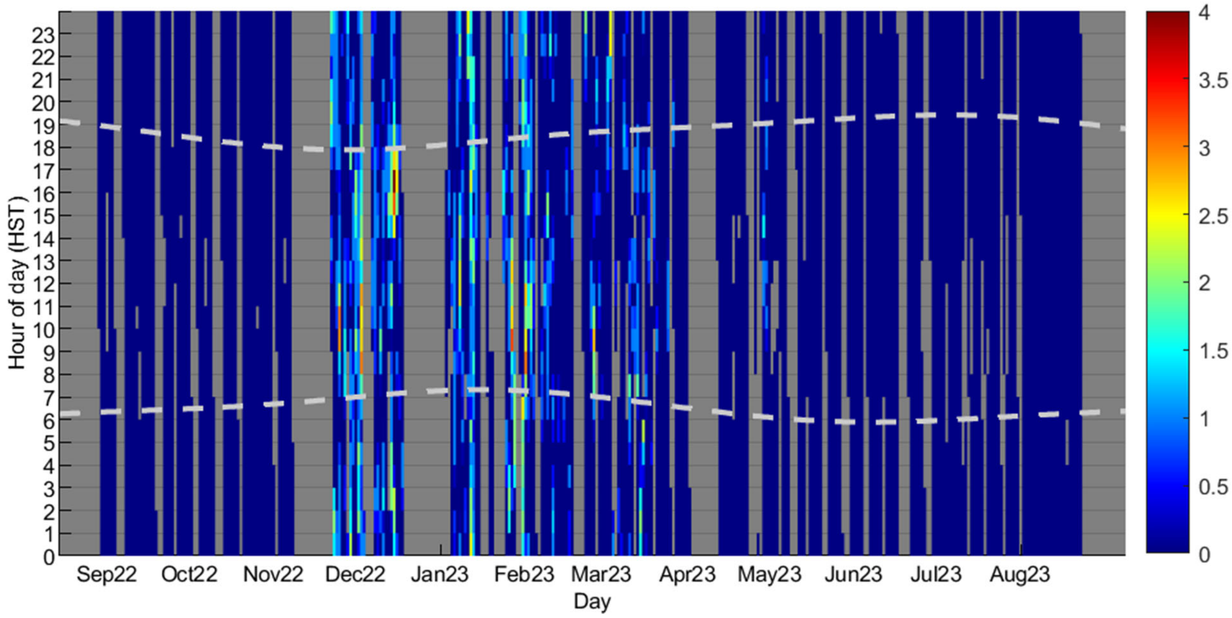
Table 4. Monthly numbers of sei whales detected in 2.5-minute snapshots.

Date	Number of Snapshots	Mean Snapshot	Standard Deviation
August-22	–	–	–
September-22	–	–	–
October-22	6,183	0.01	0.08
November-22	8,067	0.13	0.53
December-22	8,295	0.07	0.33
January-23	7,786	0.20	0.67
February-23	5,786	0.03	0.19
March-23	4,237	0.05	0.28
April-23	–	–	–
May-23	–	–	–
June-23	–	–	–

Date	Number of Snapshots	Mean Snapshot	Standard Deviation
July-23	–	–	–
August-23	–	–	–

3.2.4 Fin Whales

The mean number of automatically tracked fin whales detected in a 2.5-minute snapshot period from August 2022 to August 2023 are given for each hour of the day in Figure 7 and by month in Table 5. Fin whale song was detected from October through May. Peak monthly presence occurred in December 2022 with a mean 0.58 whales/snapshot. A peak hourly mean of 4.00 whales/snapshot occurred once in December 2022. This is in line with previously reported fin whale acoustic seasonality at PMRF which starts as early as October (Helble et al., 2020a) and ends as late at May (Martin et al., 2023). Since January 2011, presence is typically highest in December and January with up to 4 whales in a snapshot (Martin et al., 2023).



- Dark blue regions indicate periods of effort when acoustic recordings were collected and zero whale tracks were present. Results include classified data collected in February and August 2023. Gray shaded regions indicate periods of no recorded data. The light gray dotted lines indicate sunrise and sunset times.

Figure 7. The mean number of fin whales detected in 2.5-minute snapshot periods for each hour of the day from August 2022 to August 2023 ranged from 0.04 (blue) to 4 (dark red).

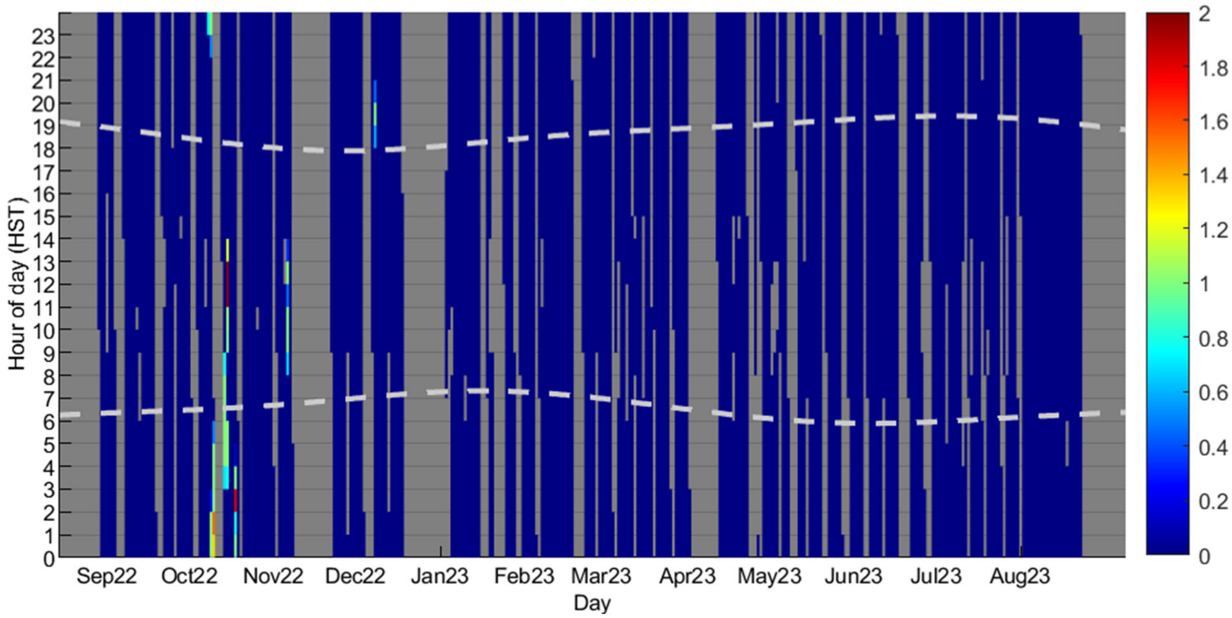
Table 5. Monthly numbers of fin whales detected in 2.5-minute snapshots.

Date	Number of Snapshots	Mean Snapshot	Standard Deviation
August-22	–	–	–
September-22	–	–	–
October-22	–	–	–
November-22	4,498	0.50	0.67
December-22	8,297	0.58	0.77
January-23	9,995	0.48	0.72
February-23	12.984	0.27	0.57

Date	Number of Snapshots	Mean Snapshot	Standard Deviation
March-23	14,699	0.14	0.39
April-23	2,025	0.09	0.30
May-23	1,005	0.08	0.28
June-23	–	–	–
July-23	–	–	–
August-23	–	–	–

3.2.5 Bryde's Whales

The mean number of automatically tracked Bryde's whales detected in a 2.5-minute snapshot period from August 2022 to August 2023 are reported for each hour of the day in Figure 8 and by month in Table 6. Bryde's whales are the only baleen whale known to potentially be present in the summer months, though this FY they were only present from October to December. Peak monthly presence occurred in October 2022 with a mean of 0.16 whales/snapshot. A peak hourly mean of 2.00 whales/snapshot occurred twice in October 2022. This concurs with general peak presence of one to two whales in a snapshot (Martin et al., 2023, 2022b). Although presence has been reported as high as three to four whales in a snapshot, it is a rare occurrence and has only occurred two other times (Martin et al., 2022a).



- Dark blue regions indicate periods of effort when acoustic recordings were collected and zero whale tracks were present. Results include classified data collected in February and August 2023. Gray shaded regions indicate periods of no recorded data. The light gray dotted lines indicate sunrise and sunset times.

Figure 8. The mean number of Bryde's whales detected in 2.5-minute snapshot periods for each hour of the day from August 2022 to August 2023 ranged from 0.04 (blue) to 2 (dark red).

Table 6. Monthly numbers of Bryde's whales detected in 2.5-minute snapshots.

Date	Number of Snapshots	Mean Snapshot	Standard Deviation
August-22	–	–	–
September-22	–	–	–

Date	Number of Snapshots	Mean Snapshot	Standard Deviation
October-22	4,786	0.16	0.41
November-22	1,483	0.07	0.26
December-22	3,255	0.02	0.12
January-23	–	–	–
February-23	–	–	–
March-23	–	–	–
April-23	–	–	–
May-23	–	–	–
June-23	–	–	–
July-23	–	–	–
August-23	–	–	–

3.2.5.1 Bryde's Whale Swimming and Acoustic Calling Behavior

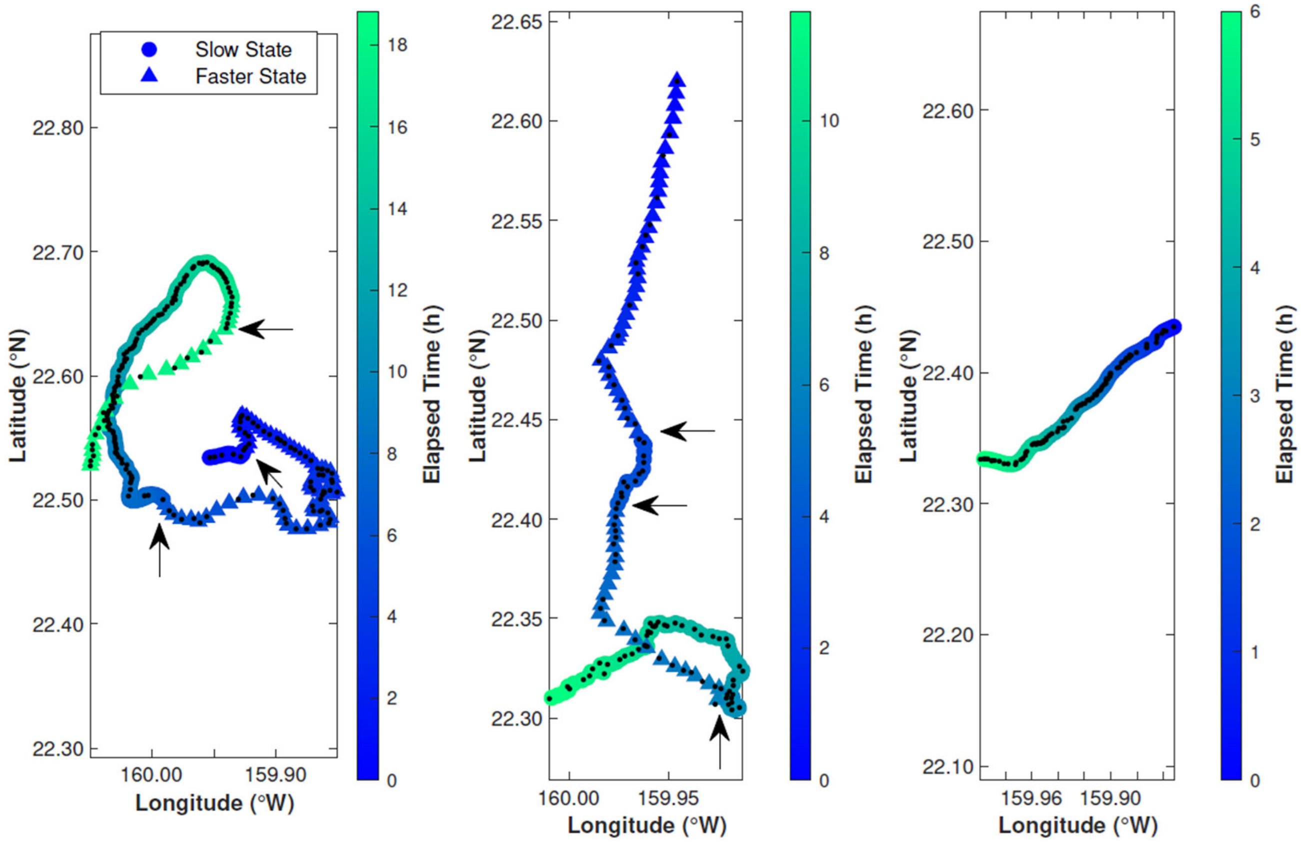
For a one-year funded LMR project, Brdye's whale acoustic and swimming behavior was analyzed for 150 whale tracks over a 12 year period on PMRF using our long-term monitoring data. Since the analysis was conducted during non-training periods, this research helps establish baseline behavior for this species and provides information on the long-term abundance of Bryde's whales on PMRF. The results from this research significantly expand the knowledge of Bryde's whale behavior in the central North Pacific, where very little has been reported on this species. A manuscript for this work was published in Frontiers in Marine Science in FY24, and is briefly summarized here.

Bryde's whale tracks were categorized into two states – a faster, more directed state (Faster State) and a slower, less directed state (Slow State) – using Hidden Markov models (HMMs). Because HMMs require inputs from equally-spaced time steps, the tracks were first resampled to generate a position every 5 minutes using the crawlWrap function of the R package momentuHMM (McClintock and Michelot, 2018), a wrapper for the continuous-time random walk (CRAWL) model of Johnson et al. (2008).

To understand the general kinematic behavior of vocalizing Bryde's whales, the mean speed, average heading, and directivity index were calculated. Mean speed is equal to the average of the 5-minute interval speeds for each track. Average heading is equal to the heading of the average of the unit vectors for each interval. Directivity index is equal to the net distance traveled divided by the cumulative distance between each 5-minute position. Overall, based on track kinematics for all 150 tracks, vocalizing Bryde's whales on PMRF traveled along fairly direct paths with little turning. The whales favored traveling toward the southwest (circular mean of average track headings = 224.3 degrees). The mean of the mean track speeds was 1.7 m/s with a standard deviation of 0.7 m/s. The median directivity index was 0.74 and the mode was between 0.9 and 1 (e.g., Figure 9).

Speed, heading, and directivity index varied as functions of days since January 1, with distinct differences between the three defined seasons of January–April, May–August, and September–December (January and December had no Bryde's whale tracks). Most of the tracks occurred in the September–December season (68%), while 23% occurred in the January–April Season, and only 9% occurred in the May–August season. The January–April season had the least directional travel, slowest speeds, and most variable headings. Though there were few tracks, the May–August season showed highly directional travel to the north, while the majority of tracks that occurred in the September–December season exhibited directional travel to the southwest. The relationship between whale swimming behavior and time was also analyzed further with HMMs.

The CRAWL tracks, spaced at even 5 min intervals, fit the original tracks well and, while infrequent, helped eliminate spurious localizations (Figure 9). Each of the 5 min intervals was categorized into kinematic behavioral state using the Viterbi algorithm, with 66% of the intervals categorized as the Slow State and 34% of the intervals categorized as the Faster State. The average speed for whales in the Slow State was 1.0 m/s and the average speed for whales in the Faster State was 2.1 m/s. The distinction between the two states seems to have been largely driven by the differences in speed rather than by turning angle (0.88 in the Faster State versus 0.82 in the Slower State). Three example tracks are shown in Figure 9, containing the original localizations (black dots) and the CRAWL-modeled positions with colored circles or triangles marking the two behavioral states (Slow and Faster). Because Bryde's whale swimming behavior is complex, no three tracks can summarize the trends from all 150 tracks. The first two tracks were selected to illustrate the performance of the CRAWL model locations compared to the original call locations, as well as illustrating state switching along a track. The third track was chosen to represent a typical Bryde's track from the dataset, with most tracks transiting in a fairly straight directional movement towards the southwest.

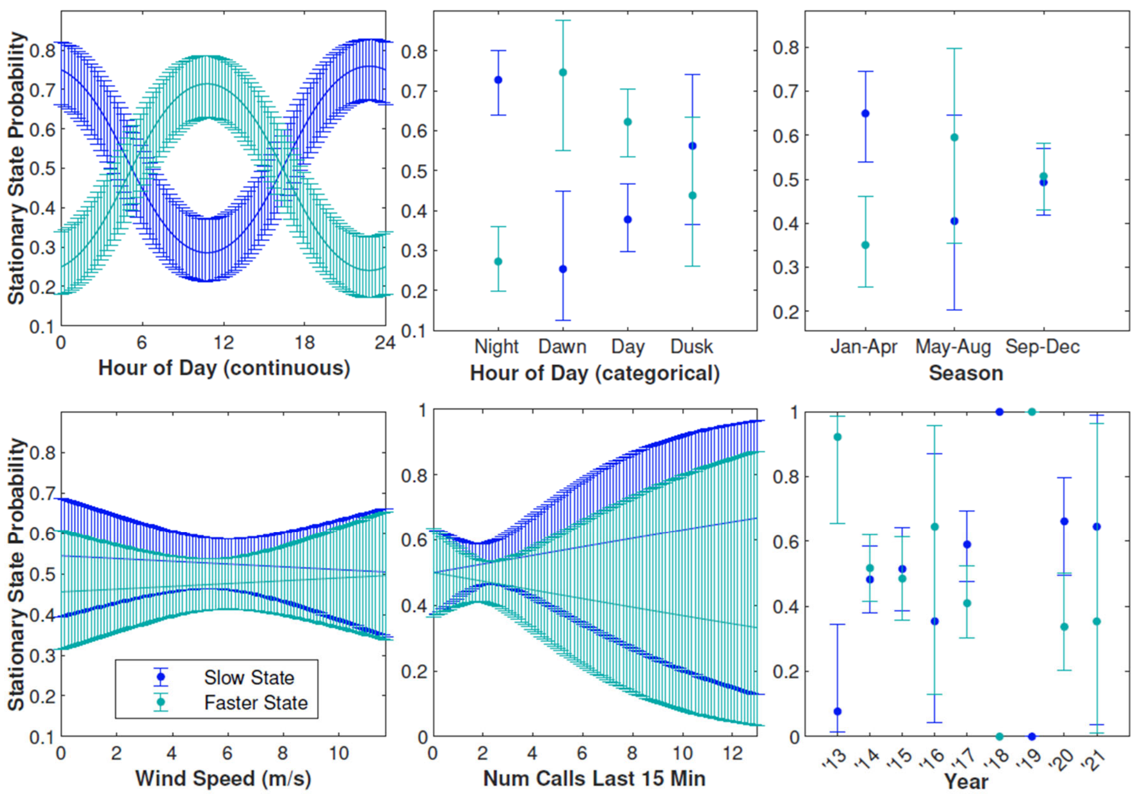


- Colored circles and triangles show the estimated whale locations on 5 min intervals with circles representing the Slow State and triangles representing the Faster State. The states were determined by hidden Markov models. Arrows indicate the locations of state changes. Color indicates time since the start of the track. Note that the elapsed time is different for each track. From left to right, these tracks started at 25 August 2014 11:47, 24 October 2014 13:46, and 24 October 2014 23:21 HST.

Figure 9. Three example Bryde's whale tracks.

Six different independent variables were tested (with one variable tested two different ways) that we hypothesized might influence Bryde's whale swimming behavior. The covariates – hour of day (continuous and categorical), season, days since Jan 1, wind speed, calling rate, and year – were each tested in their own univariate model, as well as together in multivariate models (starting with all covariates and iteratively eliminating them). Further complexities such as interaction terms or estimating random effects due to individual variation were not pursued due to the limited sample size. The stationary state probability models for six of the univariate models tested can be seen in Figure 10.

The change in the stationary state probabilities as a function of each covariate in isolation indicated that temporal variables were generally the strongest predictors of swimming state (Figure 10). Wind speed and calling rate alone both resulted in models that ranked lower than the null based on AIC scores. However, multivariate models that included the best predictors of time of year (season) and time of day (hour, continuous) did better than any univariate model, and the best of those models also included some variables that did poorly on their own. The model with the lowest AIC score included season, hour (continuous), year, and wind speed, indicating that this combination of covariates is the best predictor of Bryde's whale swimming state of those tested. The top three models are reported in Table 7, as their AIC weights were orders of magnitude above the rest but their AIC scores were within 1 point of each other.



- The blue and teal curves show the stationary state probabilities of the Slow State and the Faster State, respectively. The error bounds show the 95% confidence intervals. Plots are shown in order of AIC score from best (upper left) to worst (lower right). Wind speed, number of calls in the last 15 min, and year ranked lower than the null model. Days since January 1 is not shown because grouping the time of year variable categorically (season) was a better predictor variable for the model.

Figure 10. The probability of a 5 min observation being in the Slow State or the Faster State based on the independent variable tested for Bryde's whales.

Table 7. The top three models used to explain vocalizing Bryde's whale swimming behavior, ranked by the Akaike information criterion (AIC) and AIC weights.

Independent Variables	AIC	ΔAIC	AIC Weight
Hour of Day (continuous) + Season + Year + Wind Speed	116459	−46	0.47
Hour of Day (continuous) + Season + Year + Wind Speed + Calling Rate	116460	−45	0.30
Hour of Day (continuous) + Season + Year	116460	−45	0.24

- ΔAIC is the difference from the null model. Hour of Day (continuous) is modeled as a cosine function. Season is defined as three categories (January–April, May–August, September–December). Year is the calendar year in which the Bryde's whale was calling. Calling rate indicates the number of calls produced in the previous 15 minutes of the track.

Based on both the continuous and categorical hour of day predictor variables, there is a strong indication that Bryde's whales were more likely to swim slower at night. Bryde's whales were also more likely to be in the Slow State during the January–April season and more likely to be in a Faster State in the May–August season, although there was considerable uncertainty in the model due to the low number of samples within the latter time period. The probability of kinematic state was approximately equal during the September–December season. Year was likely included in the best model due to the high variation in number of tracks between years, though it is also possible that interannual variability in climate, food, etc. does contribute to likely swimming state in a given year (though not enough for year to perform well as a covariate on its own without accounting for variability due to other factors). While wind speed was not a strong predictor on its own, wind speed does seem to account for some variability in swimming state in the multivariate models, though it is possible that some of these final covariates in the best model are somewhat collinear and therefore overrepresented (e.g., if wind speed varies in a predictably seasonal way).

The intervals were measured between all calls for 118 of the 150 Bryde's whale tracks that were verified in Raven Pro. The overall median interval between all the tracked calls was 306 s (5.1 min) and the overall mean call interval was 361 s (6.0 min). The median call intervals within tracks increased over time at a rate of 13.1 s/year (95% CI[6.3,19.9]) (Figure 11).

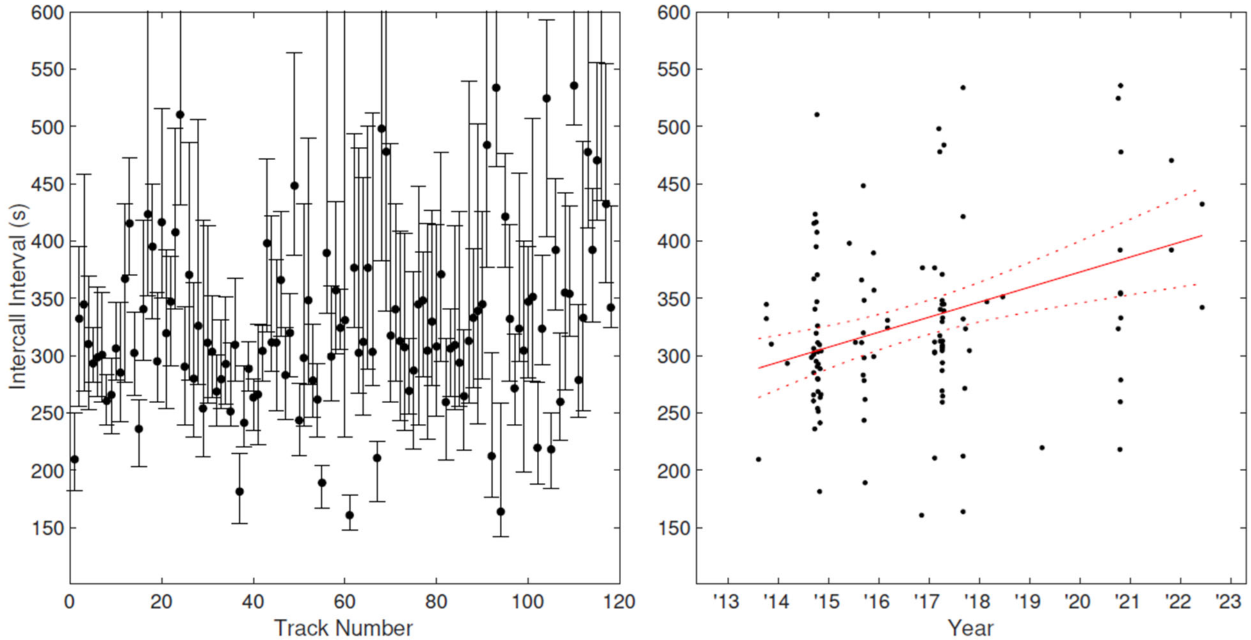


Figure 11. Bryde's whale median call interval for each track plotted both as a function of track number (left) and as a function of time (right). The error bars in the left plot extend between the 25th and 75th percentiles. A linear model was fit to the data points on the right. Dashed lines represent the 95% confidence intervals.

The along-track cue rate was calculated for 118 of the 150 tracks by summing the calls along a track and dividing the total calls by the total amount of elapsed time for the track (Figure 12). The median along-track cue rate for the 118 tracks was 22 calls/hour (Q1 = 15, Q3 = 39), and the mean along-track cue rate was 29 calls/hour. The cue rate showed a slight downward trend of -1.0 calls/year (95% CI[-2.8,0.8]).

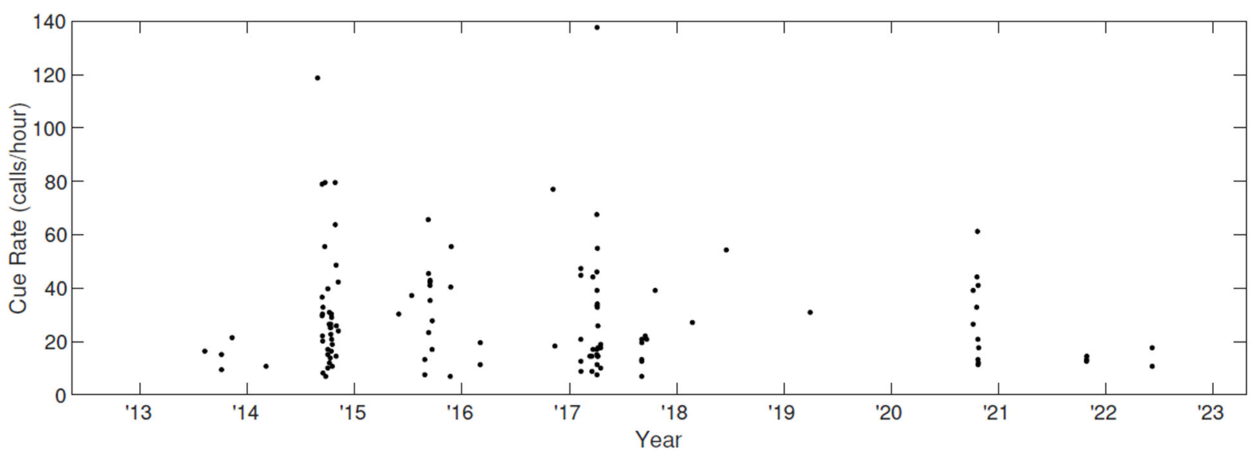
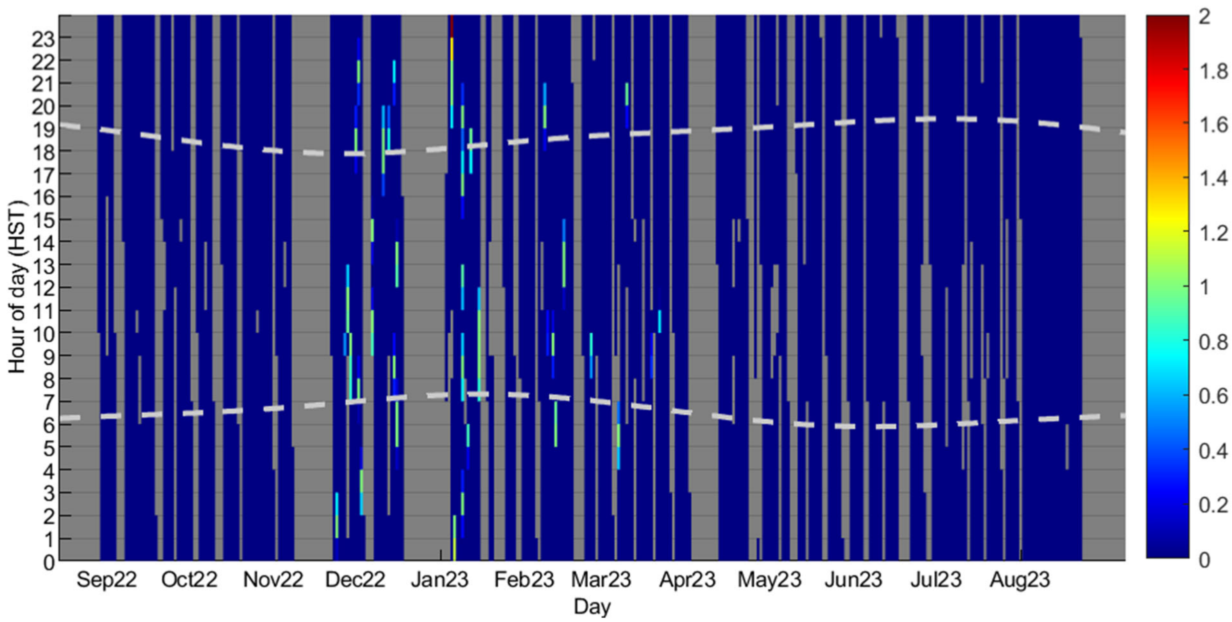


Figure 12. Along-track cue rate for Bryde's whales on PMRF as a function of time. Cue rate was calculated as number of calls along a track divided by the total elapsed time of the track and is in units of calls/hour.

3.2.6 20-Hz Downsweeps

The mean number of automatically tracked 20-Hz downsweeps detected in a 2.5-minute snapshot period from August 2022 to August 2023 are shown for each hour of the day in Figure 13 and by month in Table 8. Similar to fin whale B notes, downswept 20-Hz calls, likely produced by fin or sei whales, occurred between November 2022 and March 2023. The peak occurred in January with a maximum of 2, an hourly mean of 1.79, and a monthly mean of 0.10 tracks/snapshot. All other months with detections had lower numbers of tracks, with means between 0.02 and 0.06 whales/snapshot.



- Dark blue regions indicate periods of effort when acoustic recordings were collected and zero whale tracks were present. Results include classified data collected in February and August 2023. Gray shaded regions indicate periods of no recorded data. The light gray dotted lines indicate sunrise and sunset times.

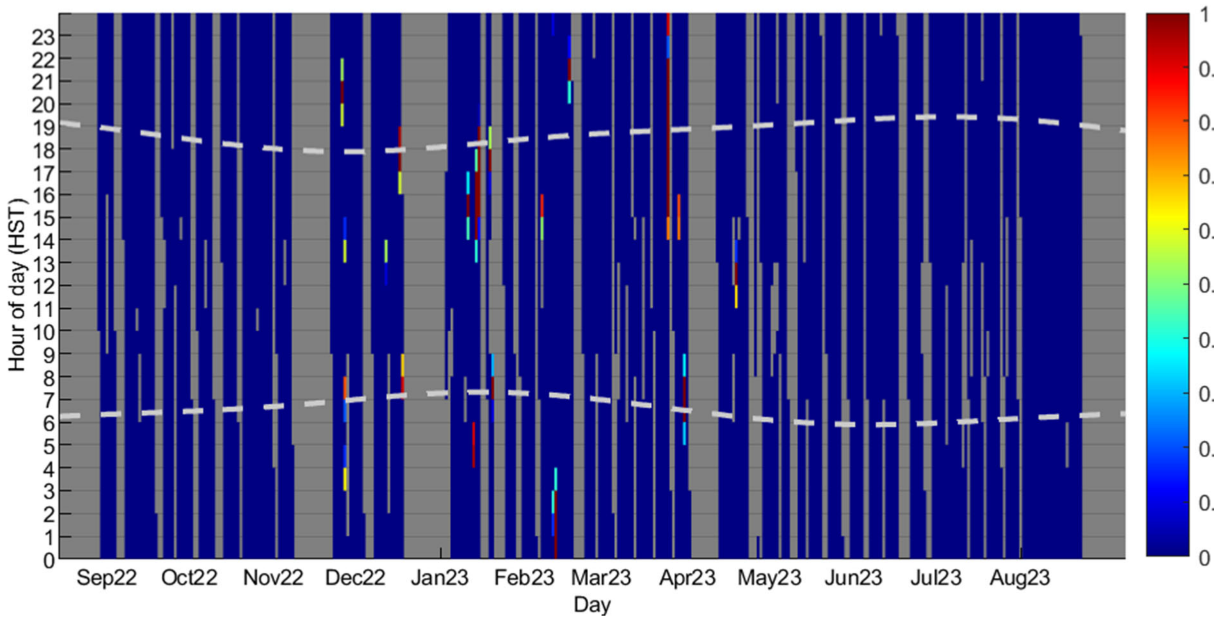
Figure 13. The mean number of tracks composed of 20-Hz downsweeps (suspected to be either fin or sei whales) detected in 2.5-minute snapshot periods for each hour of the day from August 2022 to August 2023 ranged from 0.08 (blue) to 1.79 (dark red).

Table 8. Monthly numbers of tracks comprised of 20-Hz downsweeps (suspected to be either fin or sei whales) detected in 2.5-minute snapshots.

Date	Number of Snapshots	Mean Snapshot	Standard Deviation
August-22	–	–	–
September-22	–	–	–
October-22	–	–	–
November-22	4,498	0.04	0.2
December-22	8,297	0.06	0.23
January-23	5,981	0.10	0.32
February-23	7,809	0.03	0.17
March-23	6,572	0.02	0.13
April-23	–	–	–
May-23	–	–	–
June-23	–	–	–
July-23	–	–	–
August-23	–	–	–

3.2.7 40-Hz Downsweeps

The mean number of automatically tracked 40-Hz downsweeps detected in a 2.5-minute snapshot period from August 2022 to August 2023 are shown for each hour of the day in Figure 14 and by month in Table 9. Downswept 40-Hz calls, potentially attributable to fin, sei, or blue whales, occurred between November 2022 and April 2023. Peak monthly presence occurred in January 2023 with a mean of 0.12 whales/snapshot and a maximum of two whales in a snapshot. This concurs with previously reported presence from November (Martin et al., 2022b) to March (Martin et al., 2023). A peak hourly mean of 1.00 whale/snapshot occurred 26 times from November 2022 to April 2023, with the highest occurrence in January (10 hours) and March (9 hours). Since January 2011, typically only one track consisting of downswept 40-Hz calls has occurred in a snapshot, and two tracks have been detected in a snapshot only three other times (Martin et al., 2022a). It should be noted that many of these calls likely overlap with the sei whale tracks reported in Section 3.2.3, as these are the results from the Matlab GPL algorithms and the separate sei whale results are from the new visualization tool for the results from the C++ algorithms. These parallel efforts will be merged moving forward for less redundancy.



- Dark blue regions indicate periods of effort when acoustic recordings were collected and zero whale tracks were present. Results include classified data collected in February and August 2023. Gray shaded regions indicate periods of no recorded data. The light gray dotted lines indicate sunrise and sunset times.

Figure 14. The mean number of tracks comprised of 40-Hz downsweeps (suspected to be fin, sei, or blue whales) detected in 2.5-minute snapshot periods for each hour of the day from August 2022 to August 2023 ranged from 0.08 (blue) to 1.79 (dark red).

Table 9. Monthly numbers of tracks comprised of 40-Hz downsweeps (suspected to be fin, sei, or blue whales) detected in 2.5-minute snapshots.

Date	Number of Snapshots	Mean Snapshot	Standard Deviation
August-22	–	–	–
September-22	–	–	–
October-22	–	–	–

Date	Number of Snapshots	Mean Snapshot	Standard Deviation
November-22	3,255	0.03	0.18
December-22	6,294	0.02	0.13
January-23	2,974	0.12	0.32
February-23	5,218	0.03	0.18
March-23	5,643	0.06	0.23
April-23	1,986	0.02	0.15
May-23	–	–	–
June-23	–	–	–
July-23	–	–	–
August-23	–	–	–
August-23	–	–	–

3.2.8 Blue Whales

Northwestern and northeastern Pacific blue whale calls (based on those described by Stafford et al. (2001); see also Martin et al. (2021) for example spectrograms of both call types as seen on PMRF are both known to occur in the monitoring area, though infrequently. As in previous years, these call types were automatically detected and localized using a custom Matlab GPL algorithm. The localization error of these calls is usually high due to their spectral characteristics (i.e., their long duration and relatively little frequency modulation) and the fact that they tend to occur well off-range to the north and west. Therefore, these calls are assessed for general presence rather than attempting to associate localizations into tracks.

An analyst manually validated calls from datasets containing at least 20 localizations with a maximum least squared error of 0.1. Of these, both call types were confirmed present only in early January. Northeastern Pacific blue whale calls were detected on January 3rd, 6th, 15th, and 16th while northwestern Pacific blue whale calls were detected on January 11th, 15th, and 16th. In previous years there have been instances where these two different call types occur in a regular pattern that may suggest they are produced by the same individual (though this has yet to be confirmed due to the inability to group localizations into a clear whale track), but this year, these calls co-occurred only once, and the time delays suggest that the calls belonged to different individuals.

An additional call type was noted amidst these established calls on January 3rd, 15th, and 16th and on its own on November 27th, 2022 that seemed to occur only at 54 Hz (i.e., no noticeable lower fundamental frequency; see Figure 15). Though this call is otherwise similar in character and intervals to the other blue whale call types (or at least more similar than to other known whale calls in the area), this call type does not seem to match any established blue whale call type (McDonald et al., 2006), though it is reminiscent of the 52-Hz calls from the "Watkins whale" (Stafford et al., 2007; Watkins et al., 2004). It is possible, especially with the low-frequency roll-off of the PMRF hydrophones, that it is a harmonic of a more typical call-type, as with the single Northeastern Pacific B call evident in Figure 15 in which only the harmonic between 40 and 45 Hz is visible (see also Dziak et al. (2017) about a pulsed-air model to explain this phenomenon; although if so, its frequency modulation still does not match what is typically seen for the matching harmonic in the Northwestern call as seen on PMRF). However, without visual confirmation and because the calls cannot be reliably localized into a track with other known blue whale calls, they cannot be conclusively termed blue whale calls.

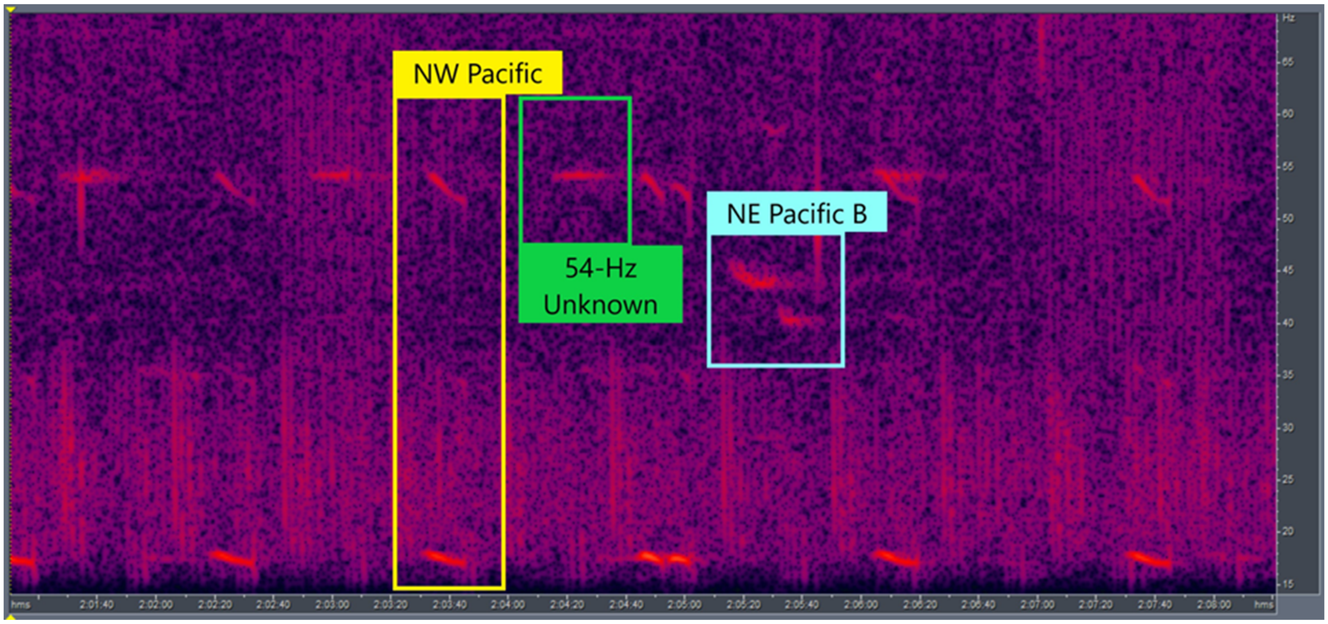
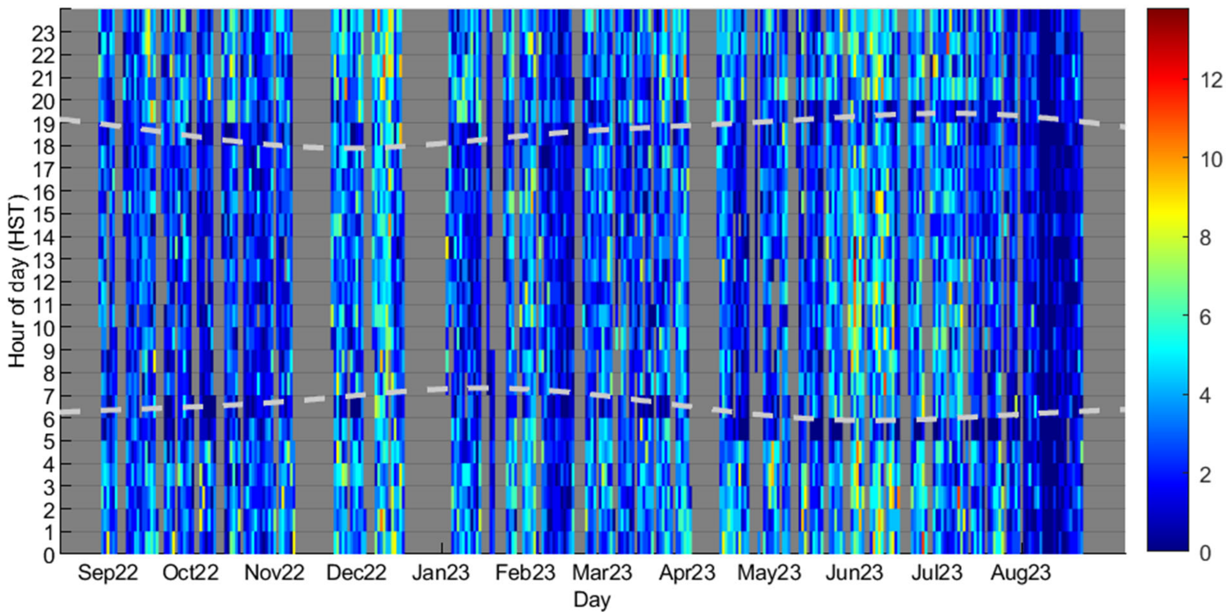


Figure 15. Example spectrogram of two blue whale call types known to occur at PMRF and one similar but unknown call type. The main call type present is the Northwestern Pacific call with a fundamental frequency at about 18 Hz. The third harmonic of a single Northeastern Pacific B call is visible between 40 and 45 Hz. Interspersed are flat tonal signals at 54 Hz which belong to an unknown species.

3.2.9 Blainville's Beaked Whales

Blainville's beaked whales were once again the most commonly detected beaked whale at PMRF, and were detected in every recording year-round. Once the detections were automatically grouped into GVPs, a subset of datasets were manually checked to determine false positive and missed dive rates and ensure the groups were sorted correctly. For Blainville's beaked whales, six 24-hour periods were randomly selected from the baseline data and two 24-hour periods were selected from SCC data for manual validation. The results from these eight periods were used to estimate average false positive rates for the rest of the recorded baseline and training datasets. The true positive rate for the FY23 baseline data was 86.1% and for the training data was 76.5%, while the false positive rate was 13.9% for baseline data and 23.5% for training data. These values were applied to the remaining autogrouped datasets and the results are visualized by hour in Figure 16 and shown by month in Table 10. The training data are also discussed separately in Section 4.2.1.

The highest GVP/hour rates occurred in June 2023 at 4.2 GVPs/hour, while the lowest dive rates occurred in October 2022 at 2.2 GVPs/hour. The mean GVP/hour rate for the year was 2.9, and the median rate was 2.8. These high rates are comparable to what was recorded in FY22 and reflect an increase in (detected) GVPs at PMRF in the last few years.



- Dark blue regions indicate periods of effort when acoustic recordings were collected and zero GVPs were present. Results include classified data collected in February and August 2023. Gray shaded regions indicate periods of no recorded data. The light gray dotted lines indicate sunrise and sunset times.

Figure 16. The total number of Blainville's beaked whale GVPs/hour corrected using manually validated dives from six unclassified datasets and two classified datasets from August 2022 to August 2023 ranged from 0.76 (blue) to 13.76 (dark red).

Table 10. Blainville's beaked whale monthly GVP summary.

Date	Number of Snapshots	Mean Snapshot	Standard Deviation
August-22	191	51.8	3.7
September-22	1444	542.1	2.7
October-22	1274	569.2	2.2
November-22	1057	336.3	3.1
December-22	1359	345.7	3.9
January-23	1238	444.2	2.8
February-23	1340	540.8	2.5
March-23	1837	612.5	3.0
April-23	971	355.5	2.7
May-23	1543	524.2	2.9
June-23	2231	535.4	4.2
July-23	1762	626.7	2.8
August-23	687	530.5	1.3

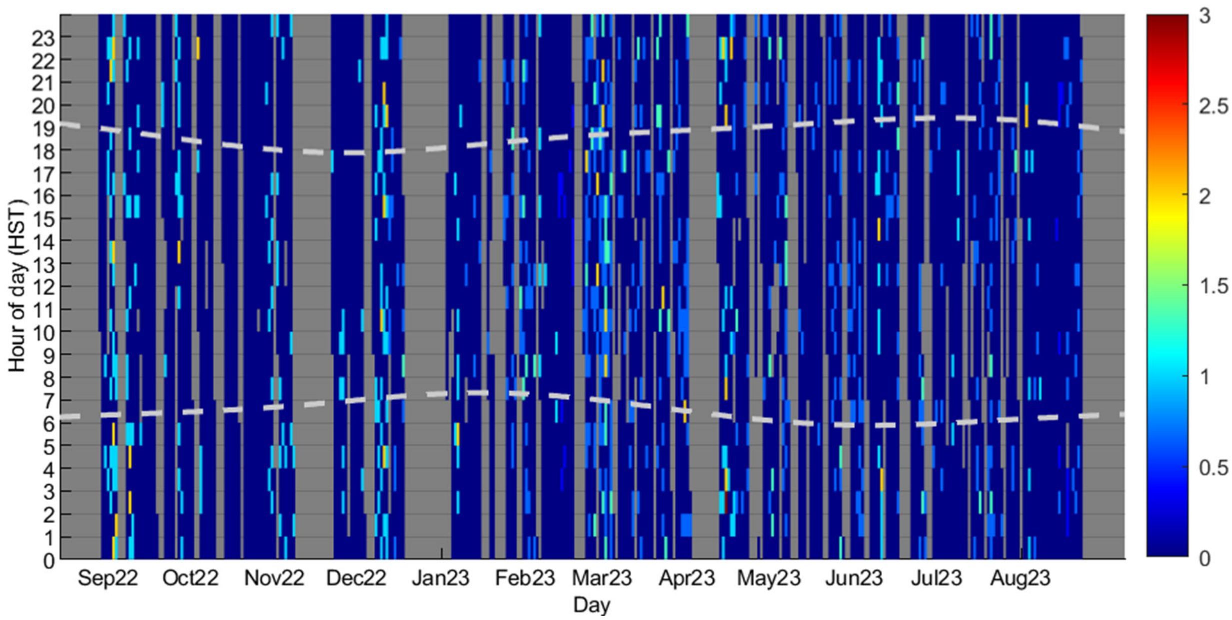
3.2.10 Cuvier's Beaked Whales

Due to the high false positive rate from clicking delphinids and the fact that the typical inter-click interval (ICI) of a Cuvier's beaked whale GVP is around 0.4 seconds (Zimmer et al., 2005), automatically associated Cuvier's beaked whale GVPs were excluded from further analysis if the mode of the ICI in the GVP was not between 0.3 and 0.6 seconds. At least one dataset per month from baseline periods was randomly selected for manual validation, in addition to one dataset per

SCC period. For these datasets, an analyst would use spectrograms to systematically review the clicks contributing to the GVPs that met the ICI criterion. The proportion of true positives from these validated datasets was used to adjust the automatically generated GVP counts for all datasets to produce the final relative abundance estimates reported in Figure 17 and Table 11. Separate true positive rates were estimated to adjust the overall GVP counts for baseline periods (66.2%) and for training periods (33.3%). The resulting numbers of GVPs adjusted by these true positive rates are summarized in Table 11 both as monthly total counts and as GVPs per hour. The training data are also discussed separately in Section 4.2.2.

During baseline periods, there were an estimated 634 GVPs total (with an additional 23 during training periods), which is lower than last year (911 confirmed GVPs) despite about 200 more hours of recording effort, but still higher than previous years, possibly due to the overall elevated recording effort (Martin et al., 2023). On average there were 0.10 GVPs/hour (median by month also 0.10 GVPs/hour), which is lower than in FY22 and FY21 (0.16 GVPs/hour for both periods) but comparable to 0.08 in FY20 and 0.09 in FY19 (Martin et al., 2021, 2022a,b, 2023). This FY, the GVP rate peaked in February (0.24 GVPs/hour), nowhere near the historic peak of 0.42 GVPs/hour in December 2021 (Martin et al., 2023), but comparable with peak occurrence in previous cycles (0.23 in July 2021, 0.19 in May 2020, and 0.24 in February 2019 (Martin et al., 2021, 2022a,b)). This suggests that the higher GVP rate in December 2021 may be an unusual event rather than indicative of some larger trend. The GVP rate was lowest in August 2022 (0.04 GVPs/hour, though this is represented by only one dataset spanning about 52 hours) and in October (0.05 GVPs/hour over about 569 hours of data), both of which were slightly higher than the last cycle’s lowest rate of 0.03 GVPs/hour in February 2022 (Martin et al., 2023). The range of hourly GVP presence is the same as last cycle, ranging from 0 to a maximum of 3 GVPs in a given hour.

Unlike the last cycle when Cuvier’s beaked whale presence seemed elevated in the summer months (Martin et al., 2023), this FY the months with the highest GVP rates were September and December 2022, and February, March, and April 2023. Thus, though it has yet to be formally analyzed, Cuvier’s beaked whales do not seem to exhibit any strong seasonal trends, although GVP rates have been consistently high in December (Martin et al., 2023, 2022b). There also continues to be no obvious diel pattern.



- Dark blue regions indicate periods of effort when acoustic recordings were collected and zero GVPs were present. Results include classified data collected in February and August 2023. Gray shaded regions indicate periods of no recorded data. The light gray dotted lines indicate sunrise and sunset times.

Figure 17. The total number of Cuvier's beaked whale GVPs/hour corrected using manually validated dives from 35 unclassified datasets and two classified datasets from August 2022 to August 2023 ranged from 0.33 (blue) to 3 (dark red).

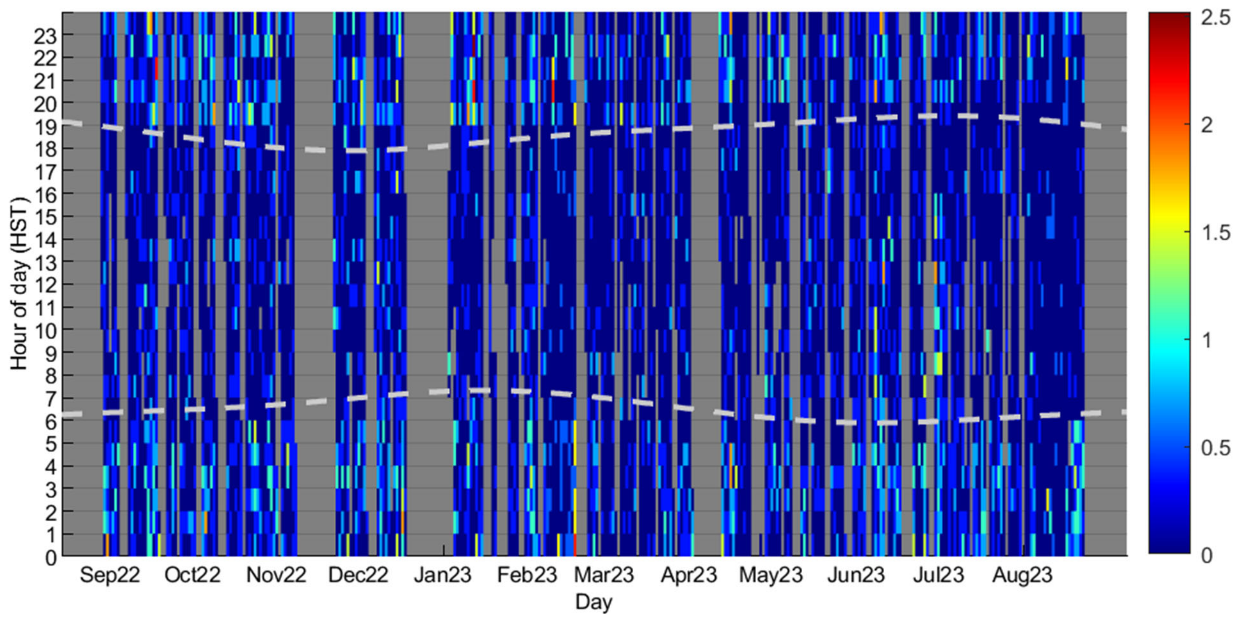
Table 11. Cuvier's beaked whale monthly GVP summary.

Date	Number of Snapshots	Mean Snapshot	Standard Deviation
August-22	3	51.8	0.06
September-22	76	542.1	0.14
October-22	32	569.2	0.06
November-22	28	336.3	0.08
December-22	52	345.7	0.15
January-23	40	444.2	0.09
February-23	71	540.8	0.13
March-23	106	612.5	0.17
April-23	50	355.5	0.14
May-23	51	524.2	0.10
June-23	59	535.4	0.11
July-23	48	626.7	0.08
August-23	30	530.5	0.06

3.2.11 Cross Seamount Beaked whales

Cross Seamount beaked whale echolocation pulses (BWC) were similarly automatically detected and grouped, with a subset of datasets manually validated. For the Cross Seamount beaked whales, at least one full dataset per month and one full dataset per SCC were validated to determine the false positive and missed dive rates. These true positive (36.3% baseline and 53.3% during training) and false positive (63.7% baseline and 46.7% during training) rates were then applied to the rest of the automatically grouped GVPs. The resulting GVPs/hour are given in Figure 18 and summarized by month in Table 12. Note that because not every dataset was manually validated this year, there are apparent detections during the day as seen in Figure 18 that are false positives but not corrected.

The highest rate of GVPs/hour for Cross Seamount beaked whales occurred in the post-SCC dataset in August 2022 (0.31 GVPs/hour) and in December 2022 (0.25 GVPs/hour), while the lowest detection rate occurred in March of 2023 with 0.12 GVPs/hour. The mean and median rates for FY23 were both 0.19 GVPs/hour. These rates are higher than what has been previously reported. In the FY22 report, the highest Cross Seamount beaked whale GVP/hour rate was 0.18 while the mean rate for FY22 was 0.13 GVPs/hour (Martin et al., 2023). In a long-term analysis of Cross Seamount beaked whale dive data, the overall mean GVP rate was 0.11 GVPs/hour. This may indicate that Cross Seamount beaked whales are occurring more frequently at PMRF. However, since only a subset of the data were manually validated this year, this high rate could just reflect that there were more false positives in the unchecked datasets than were accounted for using the validated true positive rate, as in years past all datasets were manually checked.



- Dark blue regions indicate periods of effort when acoustic recordings were collected and zero GVPs were present. Results include classified data collected in February and August 2023. Gray shaded regions indicate periods of no recorded data. The light gray dotted lines indicate sunrise and sunset times.

Figure 18. The total number of Cross Seamount beaked whale GVPs/hour corrected using manually validated dives from 14 unclassified datasets and two classified datasets from August 2022 to August 2023 ranged from 0.36 (blue) to 2.52 (dark red).

Table 12. Cross Seamount beaked whale monthly GVP summary.

Date	Number of Snapshots	Mean Snapshot	Standard Deviation
August-22	16	51.8	0.31
September-22	117	542.1	0.22
October-22	126	569.2	0.22
November-22	63	336.3	0.19
December-22	87	345.7	0.25
January-23	88	444.2	0.20

Date	Number of Snapshots	Mean Snapshot	Standard Deviation
February-23	94	540.8	0.17
March-23	72	612.5	0.12
April-23	63	355.5	0.18
May-23	78	524.2	0.15
June-23	127	535.4	0.24
July-23	103	626.7	0.16
August-23	68	530.5	0.13

3.2.11.1 Cross Seamount Beaked Whale Geographic Distribution

Cross Seamount beaked whale data from PMRF were included in an analysis of the geographic distribution of Cross Seamount beaked whales across the North Pacific, along with data from National Marine Fisheries (NMFS) surveys in the Hawaiian Islands and US West Coast, and other mobile and autonomous single-recorder platforms distributed throughout the North Pacific Ocean (Figure 19; McCullough et al., 2023). Overall, the data used in this analysis spanned 2004-2022; the PMRF contribution was from 2007-2022. Acoustic detections of Cross Seamount beaked whales were detected on all platforms, from the Mariana Archipelago to Baja California, Mexico, and from the equator to 29˚N. Of these detections, 92% occurred at night, with an additional 3% occurring during dawn and 3% during dusk periods. The remaining 2% of detections occurred during the day, indicating that very rarely do these animals echolocate during the day. Detections from the Drifting Acoustic Spar Buoy Recorders (DASBRs), which utilize two horizontal hydrophones in order to estimate the depth of the calling animals, were able to determine that these beaked whales forage relatively shallowly compared to most beaked whales, with detections occurring at depths ≤150 m. These whales also produce both the typical beaked whale echolocation pulse with a longer duration and frequency modulation, as well as a more narrow, short-duration echolocation pulse more typical of other odontocetes that appears to be used for communication. These results highlight one collaborative application of WARP's long-term acoustic dataset, where our data can be included in broader contexts to provide more information on global distribution and abundances of species detected on PMRF.

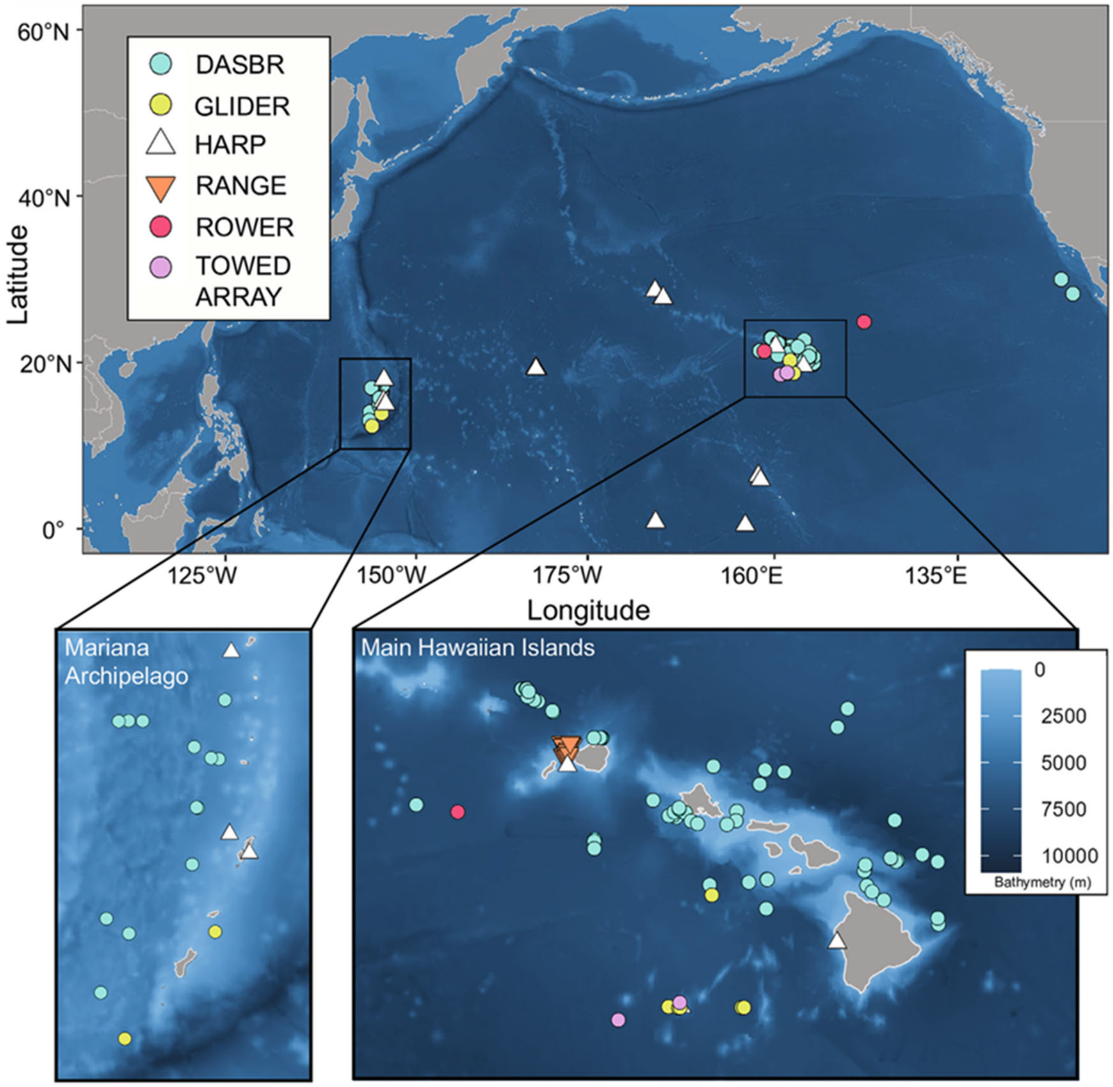
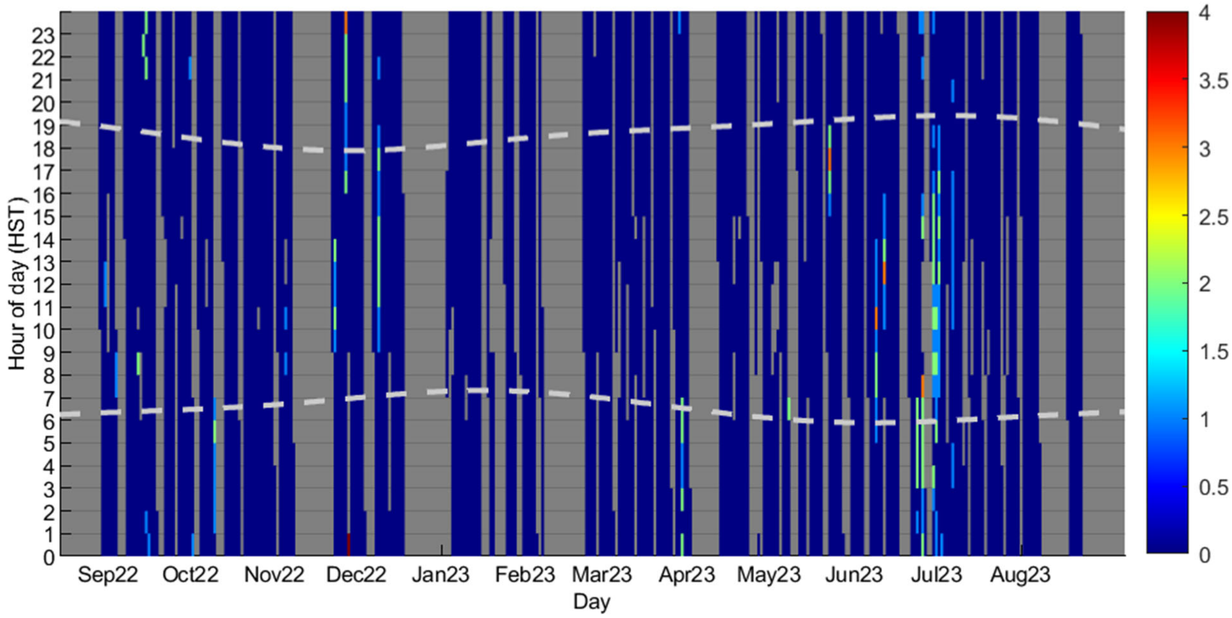


Figure 19. Cross Seamount beaked whale distribution across the North Pacific Ocean. PMRF data are shown as orange triangles. Used with permission from McCullough et al. (2023).

3.2.12 Longman's Beaked Whales

A preliminary Longman's beaked whale classifier was tested and validated on this FY's baseline data, and the results presented here for this species for the first time in Figure 20 and Table 13. As with the other beaked whale species, the detected clicks were automatically associated into GVPs based on spatial and temporal proximity. Because the automated processes produced far fewer GVPs than for any other beaked whale species, an analyst was able to validate the species ID for all GVPs, and thus the summary statistics presented are all for confirmed Longman's beaked whale GVPs. The false positive rate was extremely high (64.5%) – most often due to confusion with BWC clicks – and will hopefully be mitigated with further development that will be informed by this year of ground-truthed data.

Longman's beaked whales seem to be present on PMRF the least compared with the other beaked whale species. There were only 227 confirmed Longman's beaked whale GVPs during baseline periods, versus an estimated 634 Cuvier's beaked whale GVPs and much higher estimates for both Cross Seamount and Blainville's beaked whales. The average GVP rate was 0.04 GVPs/hour (median by month 0.03 GVPs/hour). February, April, and August had no GVPs at all. The highest GVP rate was 0.13 GVPs/hour in June, with the next highest in November 2022 at 0.10 GVPs/hour. The highest hourly rate of GVPs was 4, which happened once in November 2022. As with Cuvier's beaked whales on PMRF, there are no seasonal or diel trends immediately apparent, though any assessment of seasonality will benefit from more years of data. Longman's beaked whale clicks were most often detected on deep water hydrophones (deeper than 3 km) but were occasionally detected on hydrophones in shallower water (less than 1 km). A more detailed assessment of temporal and spatial distribution is pending as the classifier is refined and run on previous years of archived data.



- Dark blue regions indicate periods of effort when acoustic recordings were collected and zero GVPs were present. Results include classified data collected in February and August 2023. Gray shaded regions indicate periods of no recorded data. The light gray dotted lines indicate sunrise and sunset times.

Figure 20. The total number of fully validated Longman's beaked whale GVPs/hour from August 2022 to August 2023 ranged from 1 (blue) to 4 (dark red).

Table 13. Longman's beaked whale monthly GVP summary.

Date	Number of Snapshots	Mean Snapshot	Standard Deviation
August-22	2	51.8	0.04
September-22	18	542.1	0.03
October-22	23	569.2	0.04
November-22	34	336.3	0.10
December-22	16	345.7	0.05
January-23	1	444.2	0.002
February-23	0	270.4	0
March-23	11	612.5	0.02
April-23	0	355.5	0
May-23	11	524.2	0.02
June-23	70	535.4	0.13
July-23	41	626.7	0.07

Date	Number of Snapshots	Mean Snapshot	Standard Deviation
August-23	0	291.3	0

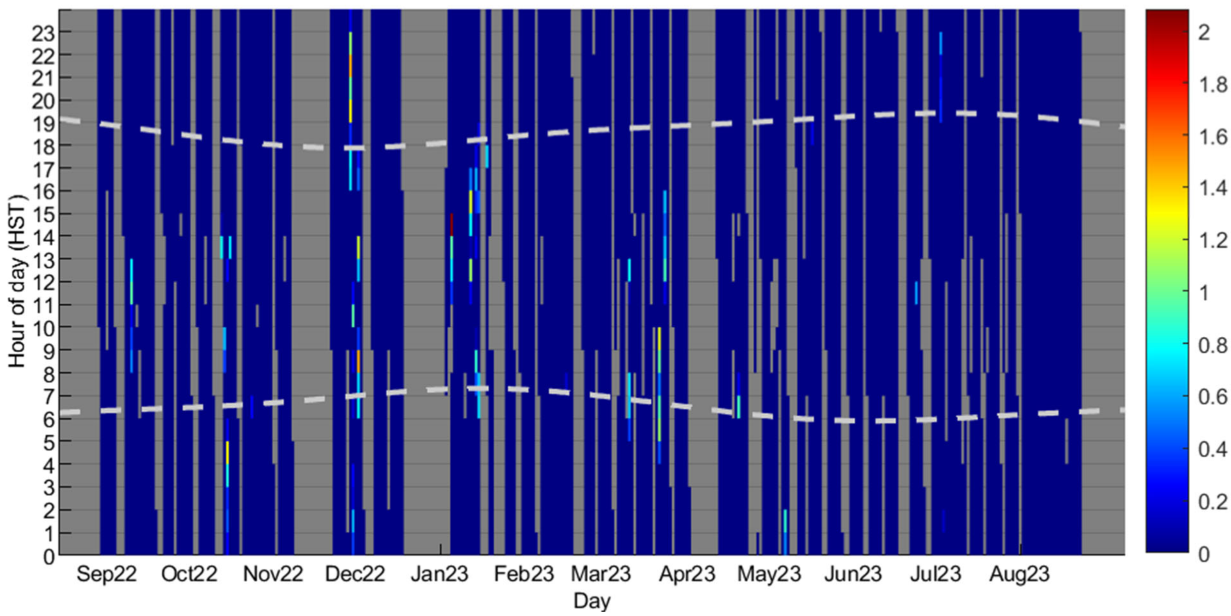
3.2.13 Killer Whales

Killer whale HFM calls (described by Samarra et al. (2010) and Simonis et al. (2012)) are occasionally detected in the PMRF area (see Henderson et al. (2018b) for example spectrograms of HFM calls as seen at PMRF). Hydrophones with HFM call detections are associated together into killer whale groups based on their temporal and spatial proximity. Due to their rarity and occasional false positive whistles from other delphinids, all groups that meet certain density and duration criteria are manually validated to confirm killer whale HFM presence. Of the automatic detections in this current cycle of data, 11 groups of killer whale HFM calls (over eight different datasets) were confirmed present. Most occurred over the summer (July 6th and 30th and August 4th and 23rd) with the remaining four on November 25th, January 24th and 30th, and June 7th. In addition, analysts on-site at PMRF witnessed killer whale HFM calls while monitoring real-time raw data starting at about midnight the morning of August 5th. These were observed in conjunction with mid-frequency echolocation clicks. As with all confirmed HFM call detections to date at PMRF, all confirmed detections this cycle occurred during daylight hours or while the moon was risen and near full, with one exception. On August 23rd there were three killer whale HFM call groups in roughly the same area that occurred about 2.5 hours apart (and therefore potentially belong to the same killer whale group), and the last of these three groups began after sundown (at about 9:30 PM) while the moon was risen but only half-illuminated.

During real-time monitoring on August 5th, the presence of the killer whale HFM calls seemed to be associated with a complete cessation of clicking by the Cross Seamount beaked whale groups the analysts were tracking (see Section 4.2.3 for more details). This cycle's contribution of confirmed killer whale groups continues to help the WARP Lab build a large enough sample size to systematically assess the behavioral responses of other monitored whales to this predator and better contextualize other behavioral responses. Based on what occurred during real-time monitoring, Cross Seamount beaked whales would seem to be a promising species with which to attempt such an assessment; however, because Cross Seamount beaked whales only click at night and killer whale HFM calls largely occur during daylight hours, such an analysis would suffer from an even smaller sample size of confirmed killer whale groups.

3.2.14 Sperm Whales

The mean number of automatically tracked, individual calling sperm whales in 2.5-minute snapshot periods from all recordings made between August 2022 and August 2023 are presented by hour in Figure 21 and by month in Table 14. Sperm whales were present year-round in all months except for August 2022 (represented by one dataset spanning about 52 hours) and August 2023. Mean monthly presence was highest by far in November 2022 (0.34 whales/snapshot), and somewhat elevated from December 2022 to March 2023 (except for February, which had an overall mean of 0.002 whales/snapshot). There was a peak mean of 2.08 whales detected in a one-hour bin once in January 2023. For comparison, in the FY22 annual report (Martin et al., 2023) monthly mean presence was highest in February 2023 and generally higher from November 2022 to March 2023. In previous reports, sperm whales have also been detected year-round, but their presence in some years does seem higher during the winter months (Martin et al., 2022a, 2023). Due to their relatively low occurrence on PMRF compared to some other species, the increase in recording effort should provide the opportunity going forward to better assess and formalize any seasonal fluctuations in sperm whale presence and/or behavior.



- Dark blue regions indicate periods of effort when acoustic recordings were collected and zero whale tracks were present. Results include classified data collected in February and August 2023. Gray shaded regions indicate periods of no recorded data. The light gray dotted lines indicate sunrise and sunset times.

Figure 21. The mean number of sperm whales detected in 2.5-minute snapshot periods for each hour of the day from August 2022 to August 2023 ranged from 0.04 (blue) to 2.08 (dark red).

Table 14. Monthly numbers of sperm whales detected in 2.5-minute snapshots.

Date	Number of Snapshots	Mean Snapshot	Standard Deviation
August-22	–	–	–
September-22	2,757	0.02	0.15
October-22	6,506	0.02	0.15
November-22	686	0.34	0.58
December-22	2,003	0.07	0.31
January-23	5,711	0.06	0.29
February-23	1,981	0.002	0.04
March-23	4,456	0.06	0.27
April-23	1,117	0.02	0.15
May-23	4,906	0.01	0.09
June-23	3,494	0.004	0.08
July-23	2,660	0.01	0.11
August-23	–	–	–

3.2.15 Noise Analysis

An analysis was conducted related to the suspected fish chorusing sounds (herein called chorusing) which were initially reported in the FY 2020 annual report (Martin et al., 2022a). Chorusing was initially observed on multiple evenings in January 2017 between approximately 1.4 to 1.8 kHz, beginning after sunset and lasting for approximately one hour. The source of chorusing is thought to be produced by lanternfish (McCauley and Cato, 2016) related to the upward vertical migration of the deep scattering layer (Martin et al., 2022a); although the species and mechanism(s) generating the chorusing sounds are unknown. Figure 22 illustrates the power spectral densities for 4 hours and 10 minutes of data beginning at 18:47 HST for a hydrophone near the center of PMRF at approximately 4 km depth on two different days in January (17th on the left and 21st on the right). The temporal focus begins about a half hour after sunset on each day. The noises are centered around 1.6 kHz with a strong increase beginning around 19:35 HST on both days. Identical settings were utilized for the two plots with the exception of the date. The chorusing onsets coincide closely with the end of astronomical twilight (i.e., when the center of the sun is 18° below the horizon).

Figure 23 presents a similar power spectral density spectrogram for the entire eight-day dataset collected mid-January 2017 for a hydrophone on north PMRF at approximately 4.6 km depth. This figure shows many features: the variability of the noise levels during periods with strong noise levels associated with wind/wave activity (highest during a storm 21-22 January) as well as the passing of vessels; suspected fish chorusing centered around 1.6 kHz occurring each evening; and minke whale boing calls with energy at around 1.4 kHz with +/- 115 Hz amplitude modulation sidebands.

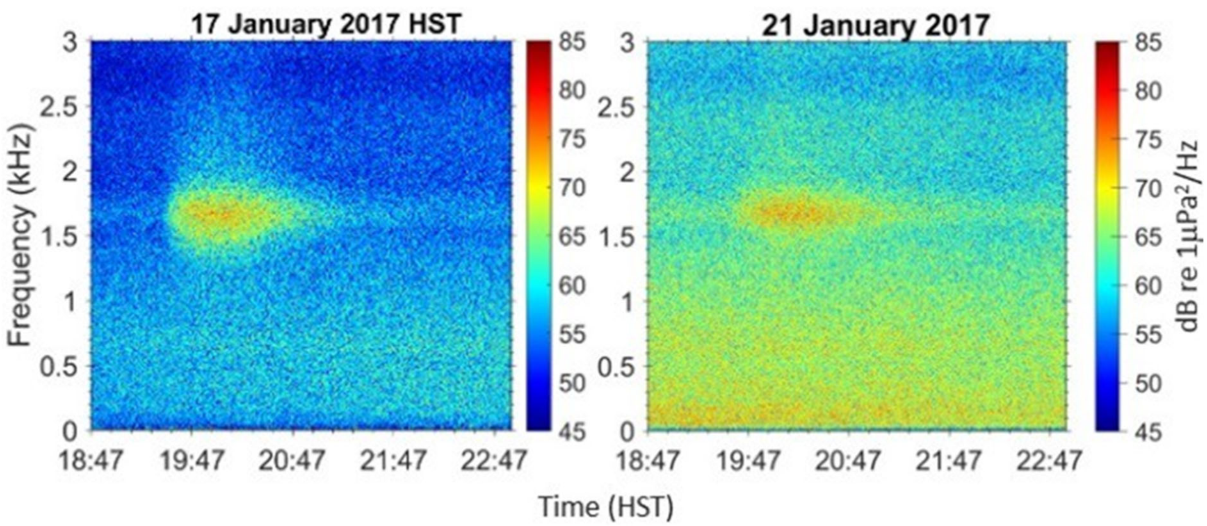


Figure 22. Power spectral density spectrogram for 4 hours and 10 minutes each on January 17 and 21, 2017.

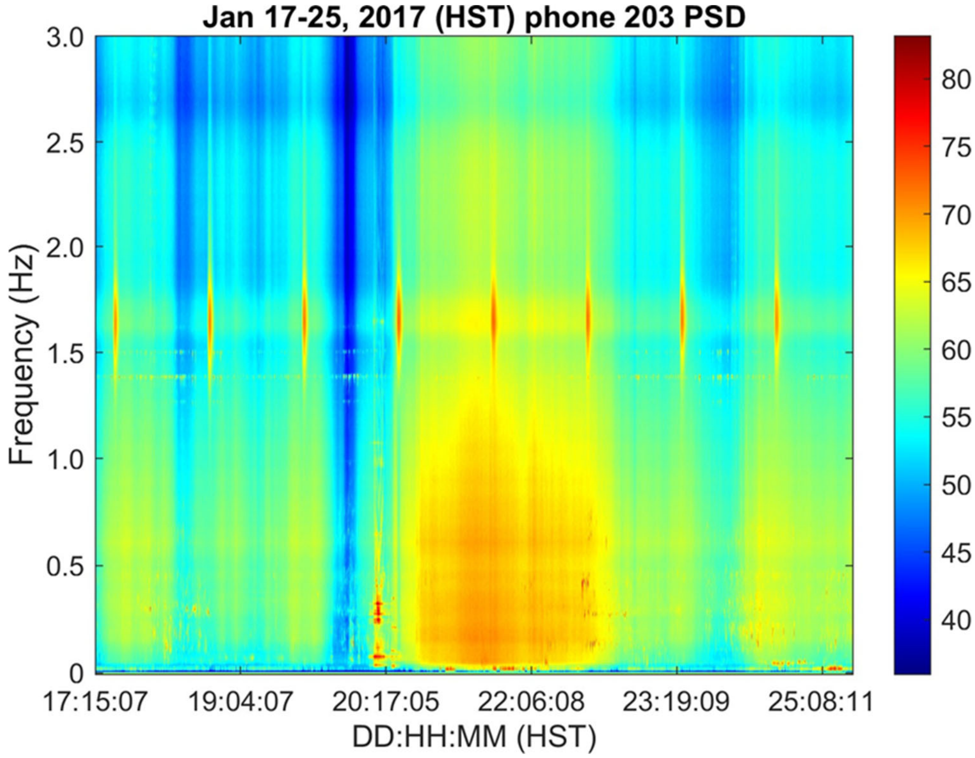


Figure 23. Power spectral density spectrogram from January 17 to 25, 2017.

The initial goal of this analysis was to determine how often the chorusing was present for the majority of available data from December 2016 through December 2017. The standard noise products are for a hydrophone near the center of PMRF at approximately 4.4 km depth and include multiple integrated spectral densities for targeted frequency bands. Chorusing was initially detected in the minke whale boing detector band (1,320-1,450 Hz). A new integrated spectral density band (the 1.6 kHz one-third octave band from 1,413 to 1,778 Hz) was found to detect the chorusing much better than the minke boing detector band (both bands shown in Figure 24). While the total bandwidth of the 1.6 kHz one-third octave band (365 Hz) captures more energy than the 130 Hz wide minke boing detection band (as evident in the overall slightly higher noise levels), it clearly captures more of the chorusing sounds as evident by the higher peaks during those sounds. It is interesting to note that the onset slope of the total energy in the 1.6 kHz one-third octave band is approximately +0.75 dB/min while the decay slope is approximately -0.19 dB/min. This makes sense if the noises are related to organisms feeding where one would suspect more feeding at the beginning and then decreasing as organisms get their fill. The -3 dB durations of the chorusing range from 45 minutes to 1 hour with the -6 dB durations ranging from approximately 1 to 2 hours. A single dataset (February 1, 2017) was also processed for six hydrophones for preliminary investigation of other higher frequency peaks associated with chorusing (D'Spain and Batchelor, 2006) and overall acoustic situational awareness. However, no other bands >3 kHz were apparent.

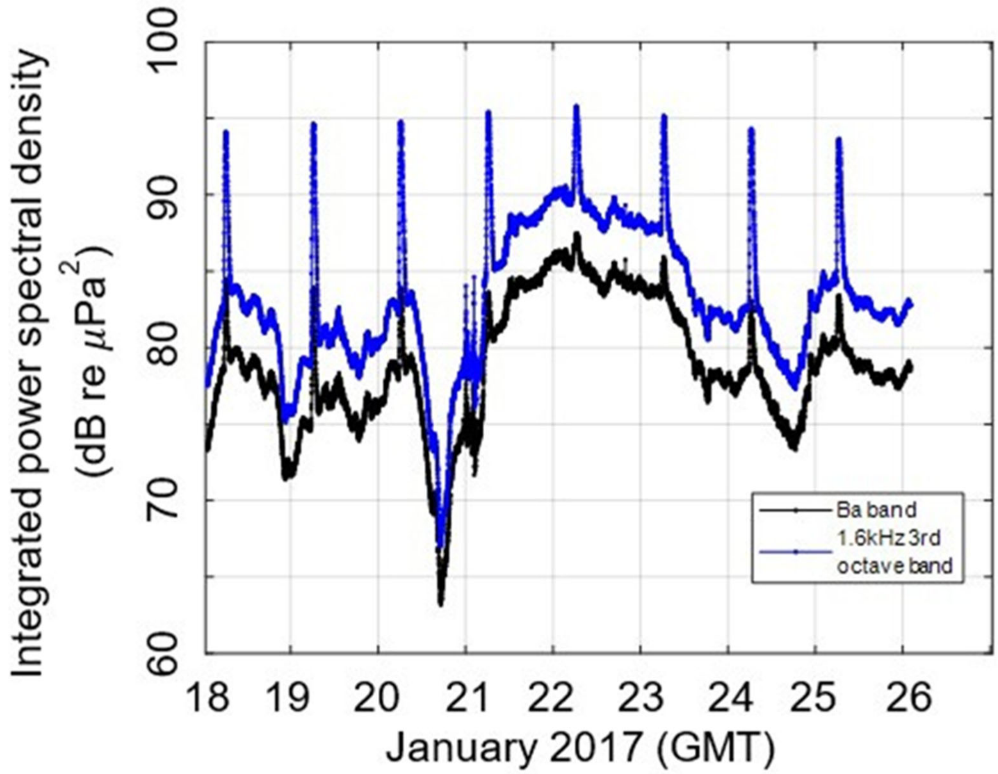


Figure 24. Comparison of two integrated spectral densities for the 18-26 January 2017 dataset for a hydrophone on north PMRF at approximately 4.6 km depth for the minke boing detection band (black) and the new 1.6kHz one-third octave band (blue).

Manual detection of chorusing peaks in the 1.6 kHz one-third octave band was readily apparent in the December 2016, and January and February 2017 data, but was challenging during periods with lower signal-to-noise ratios. Figure 25 provides the manually detectable peaks around astronomical twilight for the majority of available data from December 2016 through mid-2017. The peak level of 96 dB re 1μPa^2 occurred in January 2017 with levels over approximately 85 dB re 1μPa^2 in the 1.6 kHz one-third octave band in December 2016 and in January and February 2017. In many datasets, chorusing levels in this band were not detectable after mid-2017, which was not expected. Investigation is ongoing and examining a potential relationship between the chorusing peak levels and satellite-sensed chlorophyll a concentrations.

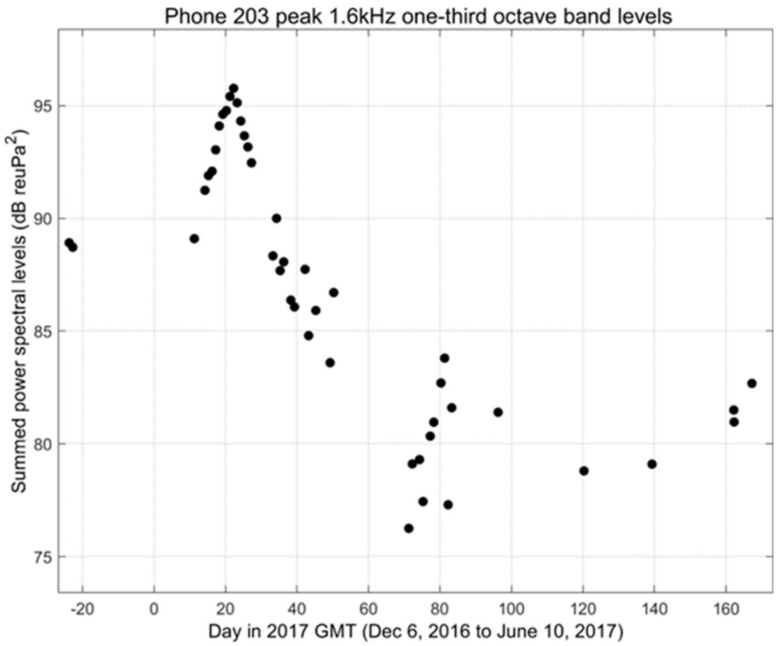


Figure 25. Peak levels in the 1.6kHz one-third octave integrated spectral densities for data from December 2016 through June 2017. The peak levels were not readily apparent in many data sets, including all after July 2017.

4. BEHAVIORAL RESPONSE ANALYSES

4.1 BALEEN WHALES

In FY23, a total of nine tracked whales were exposed to MFAS. Four fin and two humpback whales were exposed to sonobuoy transmissions only, one fin and one humpback whale were exposed to surface ship transmissions only, and one humpback whale was exposed to surface ship, sonobuoy, and helicopter-dipping sonar transmissions (Table 15). The levels presented in Table 15 represent the highest median received levels for the closest MFAS track that overlapped with a whale track. Each level was based on a single ping and estimated using propagation modeling and nominal source levels and depths. Animals are assumed to be located near the surface where they are likely to receive highest exposure levels. The median received level accounts for animal location uncertainty by summarizing received levels within approximately 100 m of an animal's location, and from 1 to 54 m of depth.

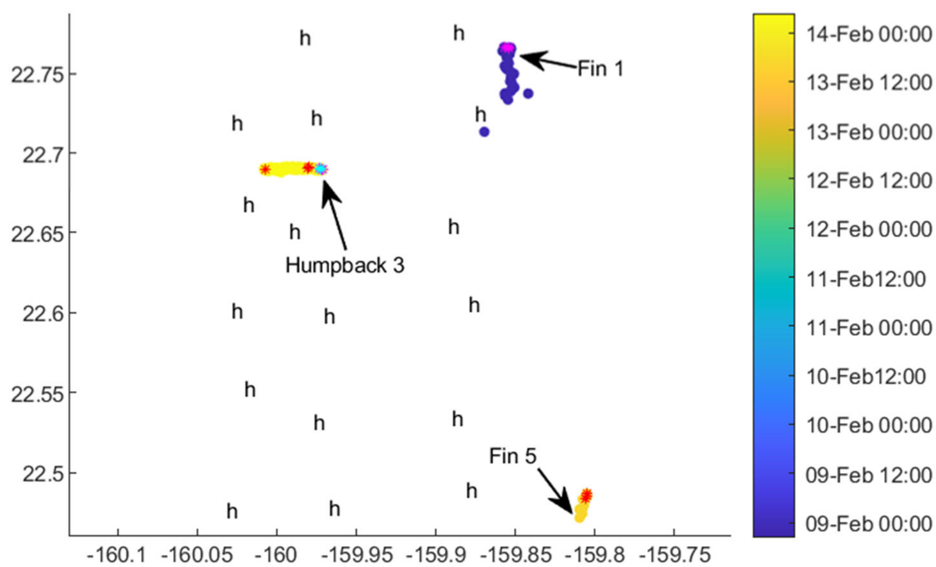
Figure 26 provides an overview of selected tracks from Table 15. Fin whale track 1 occurred during Phase A of the February 2023 SCC (no surface ship hull-mounted MFAS transmissions) and received one of the highest median sonobuoy exposures of 95.0 dB re 1µPa. Exposures to sonobuoy transmissions started on 8Feb 20:34 GMT, 16 minutes after the start of the track, and lasted for 9 minutes. During this time the distance to the closest sonobuoy increased from 27.5 to 34.1 km and there was not an apparent change in calling or movement. After sonobuoy exposures ended, fin whale track 1 continued traveling south for 1 hour and 37 minutes until the end of the whale track.

Fin whale track 5 occurred during Phase B of the February 2023 SCC (includes surface ship hull-mounted MFAS transmissions) and was the only fin whale track exposed to surface ship hull-mounted MFAS. Fin whale track 5 traveled northeast for 31 minutes before exposures began, and exposures occurred during the last 6 minutes of the track. During this time the distance to the closest surface ship transmitting MFAS decreased from 19.3 to 14.4 km and the highest median received level was 156.4 dB re 1 µPa. Although there was no apparent change in calling or movement during exposure, fin whale track 5 may have ceased calling in response to MFAS exposures, ship movement, or a combination of the two.

Humpback whale track 3 was the only track during the February 2023 SCC exposed to sonobuoys, helicopter-dipping sonar, and surface ship hull-mounted sonar. Exposures to helicopter-dipping sonar and sonobuoys occurred concurrently during the first 9 minutes of the track. During this time the closest helicopter-dipping sonar and sonobuoy transmissions were 18.1 and 12.4 km away, respectively, and the highest median received levels were 120.7 dB re 1 µPa from helicopter-dipping sonar and 87.7 dB re 1 µPa from sonobuoys. After exposures to helicopter-dipping sonar and sonobuoys ended, humpback whale track 3 did not receive any MFAS exposures for 37 minutes. Exposures to surface ship hull-mounted sonar began on 14Feb 02:33 and lasted for 4 minutes. It is during this bout of surface ship hull-mounted sonar that humpback whale track 3 received the highest median received level of 159.0 dB re 1 µPa and the closest ship transmitting MFAS was 16.1 km away. Humpback whale track 3 did not receive any MFAS exposures for 2 hours and 4 minutes after the end of the first bout of surface ship hull-mounted MFAS transmissions. The end of humpback whale track 3 coincided with resumption of surface ship hull-mounted MFAS transmissions with a highest median received level of 153.6 dB re 1 µPa and the closest ship 20.2 km away. Throughout the entire duration of humpback whale track 3, the whale was within the the instrumented range and had a consistent westerly heading. Despite a higher received level and closer distance to a ship during the first bout of exposures to surface ship hull-mounted MFAS transmissions, the whale continued to call and travel west for 2 hours and 4 minutes before suddenly ceasing to call when surface ship hull-mounted transmissions resumed. It appears that received level and distance alone did not lead to humpback whale track 3 to cease calling, and was perhaps influenced by cumulative exposures or the orientation of the ship relative to the whale (i.e., angle off the bow). Alternatively, the cessation of song may have been decoupled from the training activity and MFAS and could have resulted from a normal change in behavior, such as the singing whale joining with other whales.

Table 15. Tracked whale exposures.

Track	Start	End	Ship RL	Sonobuoy RL	Dipping Sonar RL
Fin1	**8Feb 20:18**	**8Feb 22:22**	**–**	**95.0**	**–**
Fin2	9Feb 23:53	10Feb 02:10	–	70.8	–
Fin3	10Feb 00:19	10Feb 02:27	–	95.0	–
Fin4	10Feb 21:20	10Feb 23:44	–	89.0	–
Fin5	**13Feb 16:38**	**13Feb 17:16**	**156.4**	**–**	**–**
Humpback1	13Feb 19:53	13Feb 23:25	–	88.3	–
Humpback2	14Feb 00:23	14Feb 01:01	–	86.2	–
Humpback3	**14Feb 01:47**	**14Feb 04:41**	**159.0**	**87.7**	**120.7**
Humpback4	14Feb 02:36	14Feb 02:56	156.7	–	–



- Times in GMT. Arrows point to the start of a whale track. Asterisks indicate exposure to different MFAS sources: sonobuoys (magenta), helocopter dipping sonar (cyan), and hull-mounted (red).

Figure 26. Fin and humpback whale MFAS exposures in February 2023.

4.2 BEAKED WHALES FEBRUARY AND AUGUST 2023

In FY23, data were recorded before, during, and after the February and August SCCs, as well as during a one day tracking exercise (TRACKEX) that included surface ship hull-mounted MFAS transmissions and occurred prior to both SCCs. In the February 2023 SCC, the TRACKEX was conducted as the first day of the SCC with no break between the TRACKEX and Phase A. For the August 2023 SCC, the TRACKEX was conducted three days before the SCC, and then Phase A was also broken up into two time periods with a break in between. This created three "Between" periods for the August SCC (Table 16, Table 17, and Table 18). Data were manually validated for one dataset from each SCC for all three legacy species of beaked whale (Longman's beaked whale presence during the SCCs was not assessed), and then the true positive and false positive rates were applied to the remaining During data as described in Section 3.2.9 to Section 3.2.11 of this report.

4.2.1 Blainville's Beaked Whales SCC

In the week prior to the February SCC, Blainville's beaked whales had an overall GVP/hour rate of 3.7. This decreased by almost half to 1.7 GVPs/hour during the TRACKEX and 1.9 GVPs/hour during Phase A. The GVPs didn't increase much in the period between Phases, and then further reduced to 1.2 GVPs/hour in Phase B, and remained at a lower level of 1.6 GVPs/hour in the week after the SCC. The rate then increased again to 3 GVPs/hour in March (Table 16).

Blainville's beaked whale dives were already lower than average in the week before the August SCC at 1.7 GVPs/hour. Although they went up slightly during the one day TRACKEX to 1.9 GVPs/hour, they dropped again right after to 1.6 GVPs/hour and then remained low, hovering around 0.8 - 1.0 GVP/hour for the whole SCC, and then only increased to 1.5 GVPs/hour in the week after the SCC. This reduced number of dives throughout the SCC without increases in the between periods may be due to the unusual timing of the August SCC, with activity spaced out over several days with breaks in between.

Table 16. Blainville's beaked whale GVPs before, during, and after the February and August SCCs

Period	Start Date	End Date	Duration	GVP count	GVPs/Hour
February 2023 SCC					
Before	1/30/2023 18:46	2/7/2023 20:56	163.2	600	3.68
TRACKEX	2/8/2023 0:13	2/8/2023 5:30	5.3	9	1.74
Phase A	2/8/2023 5:30	2/11/2023 5:42	72.2	134	1.85
Between	2/11/2023 5:42	2/13/2023 16:50	59	116	1.97
Phase B	2/13/2023 16:50	2/15/2023 8:02	39.2	45	1.15
After	2/15/2023 8:02	2/19/2023 6:39	94.6	147	1.56
August 2023 SCC					
Before	7/28/2023 1:30	8/4/2023 18:00	150.1	259	1.73
TRACKEX	8/4/2023 18:00	8/5/2023 3:00	9	17	1.87
Between	8/5/2023 3:00	8/8/2023 16:00	84.4	135	1.59
Phase A1	8/8/2023 16:00	8/9/2023 18:30	26.5	22	0.84
Between	8/9/2023 18:30	8/11/2023 17:00	46.5	38	0.82
Phase A2	8/11/2023 17:00	8/12/2023 0:56	7.9	7	0.87
Between	8/12/2023 0:56	8/14/2023 16:00	62.8	63	1.00
Phase B	8/14/2023 16:00	8/17/2023 20:59	77	68	0.88
After	8/17/2023 20:59	8/24/2023 8:13	152.6	228	1.50

4.2.2 Cuvier's Beaked Whales SCC

As is typical, the false positive rate for Cuvier's beaked whales during the SCCs was higher than during baseline periods (66.7% vs 33.8%), which could be due to other sources of sound or relatively lower rates of actual Cuvier's beaked whale GVPs during these periods. In general, Cuvier's beaked whale presence was highest in the week preceding each SCC, lower during, and somewhat re-elevated in the week following (Table 17). This seems more typical of beaked whale behavior than that exhibited by Cuvier's beaked whales during the SCCs the previous year, when GVP rates were higher during and after the February SCC than before, and extremely high before the August SCC before dropping to zero during the SCC and not increasing in the week following.

The estimated GVP/hour rate before the February SCC this year was 0.17, which was higher than the overall average rate (0.10 GVPs/hour) and much higher than the 0.01 GVPs/hour of the same period in the preceding year (Martin et al., 2023). There were no GVPs during the TRACKEX (possibly due to its brevity) and the average GVP rate during the SCC (including between phases) dropped to 0.03 GVPs/hour, which was the same as that during February 2022 (Martin et al., 2023). The GVP rate after the SCC was not much higher than that during, at 0.05 GVPs/hour, but then increased in March back up to 0.17 GVPs/hour.

Cuvier's beaked whales followed a similar pattern in August. Before the SCC, the GVP rate was about average at 0.09 GVPs/hour, then dropped slightly to 0.07 GVPs/hour during the TRACKEX, then further dropped to 0.03 GVPs/hour in the period after the TRACKEX. Once the first phase of the SCC began, GVP rates were no higher than 0.01 GVPs/hour until Phase B, when they climbed back up to 0.03 GVPs/hour and then appeared to increase again in the week after, back to the average rate of 0.10 GVPs/hour. There was no evident increase in GVP rates in the between periods for either SCC.

Table 17. Cuvier's beaked whale GVPs before, during, and after the February and August SCCs

Period	Start Date	End Date	Duration	GVP count	GVPs/Hour
February 2023 SCC					
Before	1/30/2023 18:46	2/7/2023 20:56	163.2	27	0.17
TRACKEX	2/8/2023 0:13	2/8/2023 5:30	5.3	0	0.00
Phase A	2/8/2023 5:30	2/11/2023 5:42	72.2	1	0.02
Between	2/11/2023 5:42	2/13/2023 16:50	59.0	2	0.03
Phase B	2/13/2023 16:50	2/15/2023 8:02	39.2	2	0.04
After	2/15/2023 8:02	2/19/2023 6:39	94.6	5	0.05
August 2023 SCC					
Before	7/28/2023 1:30	8/4/2023 18:00	150.1	13	0.09
TRACKEX	8/4/2023 18:00	8/5/2023 3:00	9.0	1	0.07
Between	8/5/2023 3:00	8/8/2023 16:00	84.4	2	0.03
Phase A1	8/8/2023 16:00	8/9/2023 18:30	26.5	0	0.01
Between	8/9/2023 18:30	8/11/2023 17:00	46.5	1	0.01
Phase A2	8/11/2023 17:00	8/12/2023 0:56	7.9	0	0.00
Between	8/12/2023 0:56	8/14/2023 16:00	62.8	0	0.00
Phase B	8/14/2023 16:00	8/17/2023 20:59	77.0	3	0.03
After	8/17/2023 20:59	8/24/2023 8:13	152.6	15	0.10

4.2.3 Cross Seamount Beaked Whales SCC

The pattern of Cross Seamount beaked whale GVPs was very typical during the February SCC. There were 0.3 GVPs/hour in the week before the SCC, which was reduced to 0.1 GVP/hour during each of the training portions of the SCC (TRACKEX, Phase A, Phase B). It increased to 0.2 GVPs/hour in the weekend between period, and increased again in the week after the SCC back to 0.2 GVPs/hour (Table 18).

The pattern of Cross Seamoun GVPs during the August SCC was a little different, with a typical number of dives detected in the week prior to the SCC (16 GVPs total for the week, with a rate of 0.1/hour), and then 3 dives during the TRACKEX for a rate of 0.4 GVPs/hour, followed by a reduced rate that varied between 0 and 0.1 GVPs/hour for most of the rest of the SCC and for the week after the SCC. The rate increased up to 0.2 GVPs/hour after the SCC (Table 18).

In the weekend period between the TRACKEX and the start of Phase A in August 2023, an effort was conducted in collaboration with Pacific Island Fisheries Science Center (PIFSC, part of NOAA) and Cascadia Research Collective (CRC) to visually and acoustically identify the Cross Seamount beaked whale in order to determine what species produces this specific echolocation pulse. Since this is the only species of beaked whale that echolocates only at night, overnight operations had to be conducted on the range to locate and then keep track of Cross Seamount beaked whale GVPs. This information was then communicated to the PIFSC team onboard the R/V Sette, who then maneuvered to the location of the echolocating group and tried to detect the whales on their own hydrophone array. This worked very successfully on the night of August 4, with multiple Cross Seamount beaked whale groups detected across the range and the R/V Sette co-locating several of the groups. The last Cross Seamount beaked whale GVP detection occurred at 3:28 (HST). Unfortunately, a group of killer whales that had been moving across the range to the north of the Cross Seamount beaked whale groups since around 23:30 turned to move southwest at around 2:30 HST and began moving towards the Cross Seamount beaked whale groups. The Cross Seamount beaked whales stopped vocalizing and did not echolocate again for the rest of the night. The PIFSC team was able to get photographs of the killer whales in the morning, but did not see any beaked whales. There were no Cross Seamount beaked whale GVPs the following night, and then the R/V Sette had to leave the area. However, the concept of detecting Cross Seamount beaked whale GVPs using the range hydrophones and maneuvering a vessel to those positions was proven to be successful and would likely have resulted in a species identification if the killer whales had not driven away the beaked whales. It would be worth revisiting this type of effort in the future as it is likely to be the best way to find and identify this species.

Table 18. Cross Seamount beaked whale GVPs before, during, and after the February and August SCCs

Period	Start Date	End Date	Duration	GVP count	GVPs/Hour
February 2023 SCC					
Before	1/30/2023 18:46	2/7/2023 20:56	163.2	43	0.27
TRACKEX	2/8/2023 0:13	2/8/2023 5:30	5.3	0	0.00
Phase A	2/8/2023 5:30	2/11/2023 5:42	72.2	6	0.09
Between	2/11/2023 5:42	2/13/2023 16:50	59	13	0.22
Phase B	2/13/2023 16:50	2/15/2023 8:02	39.2	3	0.07
After	2/15/2023 8:02	2/19/2023 6:39	94.6	17	0.18
August 2023 SCC					
Before	7/28/2023 1:30	8/4/2023 18:00	150.1	16	0.11
TRACKEX	8/4/2023 18:00	8/5/2023 3:00	9	3	0.36
Between	8/5/2023 3:00	8/8/2023 16:00	84.4	12	0.14
Phase A1	8/8/2023 16:00	8/9/2023 18:30	26.5	2	0.08
Between	8/9/2023 18:30	8/11/2023 17:00	46.5	5	0.10
Phase A2	8/11/2023 17:00	8/12/2023 0:56	7.9	0	0.00
Between	8/12/2023 0:56	8/14/2023 16:00	62.8	6	0.09
Phase B	8/14/2023 16:00	8/17/2023 20:59	77	6	0.08
After	8/17/2023 20:59	8/24/2023 8:13	152.6	31	0.20

5. CONCURRENT AND RELATED EFFORTS

5.1 LMR BREVE TRANSITION

Progress was made in the area of estimation of received levels from MFAS sources, now including both helicopter dipped MFAS and sonobuoy MFAS. A new method to determine MFAS activity was developed and MFAS tracks are being created for three sources of MFAS (surface ship, helicopter and sonobuoy platforms). In addition, new down-selection processes allow for automated representation of the vast majority of all MFAS transmissions. The down-selection process allows for received level estimates for each platform producing MFAS in each 5 min bin using the Peregrine propagation modeled received levels for MFAS transmissions close in space and time. Cumulative sound exposure levels are also estimated for each 5 min bin, rather than representing over the entire whale track duration. These acoustic exposure metrics will be applied to minke whale exposure data utilized by Durbach et al. (2021) for expanded analysis.

5.2 LMR BRYDE'S WHALE CUE RATES AND KINEMATICS

The goal in this study was to analyze Bryde's whale swimming behavior and acoustic presence in Hawaiian waters. Bryde's whales are a relatively understudied megafaunal species, with very few measurements of their seasonal presence or kinematic behavior. By monitoring them in relatively undisturbed waters (no US Navy exercises were conducted during the study period and vessel noise is limited), we can examine natural variations in Bryde's whale acoustic and kinematic behavior.

Understanding these variations is vital to being able to make conclusions about the severity of behavioral changes during anthropogenic disturbance. As described in more detail in Section 3.2.5, a total of 150 vocalizing Bryde's whales were tracked for 12 years over a 20x58 km area off Kaua'i, Hawai'i using a bottom-mounted array of hydrophones. The speed and directivity of these tracks were analyzed with statistical software to automatically classify track segments into slow or faster kinematic states. HMMs were used to examine these kinematic states relative to calendar year, day of year, season, hour of day, wind speed, and calling rate. Findings indicate that Bryde's whales were more likely to travel in a faster and more directional state during daytime hours and in certain seasons. The along-track cue rate for 118 of the tracks was also measured and provides vital information for eventually using acoustic cues to estimate the density of animals using passive acoustic monitoring. The types of calls recorded and the intervals are also reported, which is helpful for understanding the linkages between populations of Bryde's whales in the North Pacific. A manuscript for this work was published in Frontiers in Marine Science in FY24 (Helble et al., 2024).

5.3 TAGGING AT PMRF

Cascadia Research Collective (CRC) conducted satellite tagging of odontocetes on PMRF August 5-13, 2023. They also were onsite to participate in the Cross Seamount beaked whale species identification effort along with PIFSC, and had the whales been located would have tagged them. The *R/V Sette* collaborated with CRC on August 5 to help locate groups of odontocetes for tagging, in conjunction with NIWC Pacific, and Naval Undersea Warfare Center Newport to locate animals on the range. Ten total tags were deployed on short-finned pilot whales (6), bottlenose dolphins (2), melon-headed whales (1), and pantropical spotted dolphins (1). In addition to supporting the tagging effort at PMRF, in FY23 NIWC Pacific also worked with CRC to analyze the satellite tag data from the 2021 and 2022 field seasons. One report was written on the estimation of received levels for 15 tagged odontocetes, including pilot whales, false killer whales, melon-headed whales, rough-toothed dolphins, and bottlenose dolphins. In addition, a separate and more in-depth analysis was conducted on four tagged Blainville's beaked whales, including received level estimation and behavioral response analyses applied to both dive and horizontal movement behavior. This effort was summarized in a paper that will be submitted to a peer-reviewed journal.

5.4 SMART/LMR LARGE WHALE BEHAVIOR IN THE NORTH ATLANTIC

The scope of this study focuses on the acoustic behavior of fin whales in the North Atlantic. Fin whale song patterns were analyzed over 10 years and compared to song patterns that have been observed in the North Atlantic and North Pacific Oceans. This analysis was modeled after Helble et al. (2020a), with the aim that the results from these two papers will be directly comparable. Fin whale population size, structure, distribution, and connectedness are not well understood, but passive acoustic monitoring is a tool that could be applied to improve management decisions for this species. For this work, US Navy arrays in the North Atlantic were used to record fin whale songs from 2013–2023, define song patterns, and identify changes over time. Inter-note intervals were observed to increase over both inter- and intra-annual timescales. Since passive acoustic monitoring has been suggested to estimate abundance or density, two different options were examined for "cues" (individual notes and longer gaps between song bouts) and stability over time and between ocean basins were compared. In addition, an upsweep note has been observed to be decreasing in frequency for at least 30 years. A manuscript for this work was published in Frontiers in Marine Science in FY24 (Guazzo et al., 2024).

5.5 ONR TRACKING ODONTOCETES ON PMRF

In collaboration with researchers at the University of Hawaiʻi (UH), the WARP lab has identified multiple groups of odontocetes that have vocalized while crossing the PMRF range, including sperm whales, killer whales, pilot whales, and rough-toothed dolphins. During these periods of vocalizations, every hydrophone on the range was manually checked to determine if it included vocalizations from the focal group, and to ensure that no Navy signals were included in the data. Once the data were thoroughly scrubbed, the raw acoustic data from the hydrophones that included focal group vocalizations were compiled and shared with UH. The UH researchers are developing algorithms to detect odontocete groups on large arrays, and PMRF is an ideal large array to derive datasets used to train and test the algorithm. Once the algorithm is developed, it can be integrated into the NARWHAL algorithm suite so that WARP can begin tracking odontocete groups.

5.6 BOEM TAG DATA COLLABORATION

In a BOEM-funded effort led by Oregon State University, a number of organizations (including NIWC Pacific) have shared satellite tag data from different baleen and odontocete species in Hawaiian and US West Coast waters. The goal of the project is to use the combined tag data to determine where hotspots of behavior – including foraging, breeding, or migration – may occur that could overlap with potential future wind energy development sites. These results will directly determine BOEM's management and leasing of those areas as wind energy development begins in these regions of the US. The tag data supplied by NIWC Pacific is from the PACFLT-supported effort to tag humpback whales off Kauaʻi.

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